EFFECT OF TEMPERATURE AND DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON AVAILABLE NITROGEN AND CARBON DIOXIDE RELEASE IN AKAKA SOIL

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

The available nitrogen in the soil is considered to be a very important essential nutrient for plant growth. It stands out as being very susceptible to microbial transformation. Generally, the quantity of available nitrogen in soil fluctuates quite readily due to various factors, such as: soil moisture, soil temperature, soil reaction, and biological activities in soil. A great deal of attention has been focused on the microbial transformation of organic nitrogen to ammonium and nitrate forms. The evolution of carbon dioxide has been used by a number of investigators as an index of the decomposition of organic matter in the soil. The evolution of CO_2 is largely dependent on the biological life of the soil, and most investigators believe that the activities of microorganisms are the main source of CO_2 release.

The nitrogen liberated by microbial transformation of organic nitrogen can be measured as ammonium and nitrate nitrogen. On the other hand carbon dioxide is liberated from carbonaceous materials. Although nitrite is sometimes detectable, in general, its content in soil is very small in comparison to the amount of ammonium and nitrate fractions. So it is usually assumed that the quantity of nitrite which is present in the soil is not sufficient to warrant its determination (Bremner, 1969). However nitrite accumulation has been found in alkaline soils when high rates of ammonium fertilizer are applied (Martin, et al., 1943; Fuller, et al., 1950; Chapman and Leibig, 1952; Duisberg and Buehrer, 1954; Broadbent, et al., 1957; Stojanovic and Alexander, 1958; Aleem and Alexander, 1960).

Temperature likewise affects the mineralization of organic nitrogen

because it affects microorganism growth. At low temperature the rate of mineralization is slow and when the soil is frozen, ammonification and nitrification rates are nil. Increasing the temperature will produce more ammonium oxidation until an optimum range is attained (Frederick, 1956; Alexander, 1961; Parker, et al., 1962; Aref'yeva, et al., 1964; R-Etinger-Talczynaka, 1969; Sabey, 1969; Sabey, et al., 1969). In contrast to other microbiological transformations, the optimum temperature for the ammonification process is above the mesophylic range (30° - 35°C), and usually lies between 40° and 60°C. In organic matter decomposition, ammonium accumulation can occur at 65°C due to the activity of thermophylic organisms (Alexander, 1961).

This investigation was carried out to gain further knowledge on the effect of various soil factors and their interaction on available nitrogen and carbon dioxide release in an amorphous Hawaiian soil. There is little past work on this aspect of nitrogen study. Some of the factors and effects have been studied by Thiagalingam (1967) on the effect of temperature and biological control chemicals on nitrogen transformation in three Hawaiian soils. Agarwal (1967) and Singh (1968) have studied the effect of chloride salts on ammonium nitrogen release in two Hawaiian soils. Thiagalingam worked with three incubation temperatures, 5.25° and 40°C, and he found that nitrification rate of ammonium sulphate was influenced by temperature. Ammonia oxidation rate was most rapid at 25°C, although the process took place also at the other two temperatures. Agarwal and Singh worked with chloride salts that ranged in concentration from 0.001 to 1.0 molar; they found that ammonium release in the soil generally increased with increasing

concentration of chloride salts, except when 1.0 M concentration of di- and tri-valent cation chloride salts were added to the soil. The amount of ammonium nitrogen release decreased with increasing cation valence of chloride salt, when the concentration was greater than 0.1 M. For a di-valent cation chloride salt, when 1.0 molar concentration was added, the amount of NH_4-N release in the first two weeks of incubation was smaller than at a concentration of 0.1 M. The release became greater in the last two weeks of incubation with the tri-valent chloride salts; this decrease in NH_4-N release at the 1.0 molar concentration persisted throughout all incubation periods.

The results of the above investigation brought up some very interesting points that led to this present investigation. There appeared a need to extend those studies to wider ranges of temperatures and chloride salt concentrations and to determine ensuing effects on available nitrogen and carbon dioxide release. The extent to which microbial activities and chemical transformations contribute to available nitrogen release when salts are added was also looked into. The main objectives of the present study were to investigate:

1. Effects of different concentrations of chloride salts on available nitrogen and carbon dioxide release in Akaka soil at room temperature.

2. Effects of different concentrations of chloride salts on available nitrogen and carbon dioxide release at different temperatures.

3. Effect of sterilization on available nitrogen and carbon dioxide release in Akaka soil with different concentrations of sodium chloride salt.

REVIEW OF LITERATURE

The conversion of organic to inorganic nitrogen is termed "mineralization." That portion of mineralization in which organic complexes are decomposed and nitrogen is liberated as ammonium, is known as "ammonification." The further conversion of ammonium to nitrite then to nitrate is referred to as "nitrification." Ammonification proceeds under a variety of conditions and is participated in by numerous types of microorganisms. Nitrification is considered to be a consequence of the activity of a limited number of specific microorganisms under suitable soil conditions. Carbon dioxide evolution has frequently been used as an index of the decomposition of organic matter in the soil and as a measure of microbial activity (Waksman and Starkey, 1924). Carbon dioxide evolution from the soil and its relationship to microbial activity and to other factors have been studied by a large number of investigators (Lundegårdh, 1924; Waksman and Starkey, 1924; Stoklasa and Ernest, 1905; Suchtelen, 1910; Pettersen, 1870; Gainey, 1919; Russell and Appleyard, 1915; and others). They have found a relation between the carbon dioxide evolution on the one hand and the number of bacteria and the intensity of nitrification on the other hand.

Wollny (1880) found that the carbon dioxide content of the soil increase or decrease with the amount of organic matter present in the soil. Kiszling and Fleischer (1891) reported that temperature is one of the most important factors that stimulate organic matter decomposition. Déhérain and Démoussy (1896) stated that the formation of carbon dioxide was due almost entirely to the action of

microorganisms, and the amount of CO_2 liberation increased with temperature to about 65°C, then decreased, and at 90°C another increase took place due to chemical activities. Even in sterile soil, small amounts of carbon dioxide were liberated from the soil (Severin, 1910-1912). Beside this, Lundegårdh (1927) assumed that two-thirds of all the carbon dioxide present in the soil air are formed as the result of microbial activity while one-third is released by the plant roots.

The presence of organic matter and the influence of temperature were found to be of great importance. Stoklasa (1905, 1912) found that production of CO_2 was in direct proportion, not to the total carbon content of the soil, but to the available organic matter in the soil. Also, the amount of carbon dioxide produced was found to depend on the quantity and kind of organic matter, physical and chemical conditions of the soil, and number and kinds of microorganisms. The intensity of carbon dioxide production was found to be very great at the beginning of an incubation experiment and rapidly decreased after a short period (van Suchtelen, 1910). That worker also concluded that the number of microorganisms, cultivation, aeration, and nutritive salts exerted stimulating effects on carbon dioxide production. Russell and Appleyard (1915) found that a rise in the CO_2 content in the soil air and somewhat later by a rise in nitrate in the soil. Gainey (1919) observed parallel formation of carbon dioxide, ammonium and nitrate from organic substances, when moisture and aeration were favorable; the correlation was especially noticeable between ammonia and carbon production. It will be shown elsewhere that the relative amounts of carbon dioxide and ammonia formed from any organic substance depend

upon the metabolism of a particular organism and the carbon-nitrogen ratio of organic material. For every unit of carbon assimilated by the organisms, as well as for the carbon dioxide formed, there is a definite amount of nitrogen assimilated. Neller (1918) and Gainey (1919) showed evidence that when organic matter contains more nitrogen than the organisms need for metabolism, a part of nitrogen will be left as a waste product in the form of ammonia; when the organic matter contains less nitrogen than the organisms require, there will be no ammonia accumulation and carbon compounds will be decomposed only so far as the nitrogen supply, whether present in the material or added in inorganic forms, will permit.

Artyushenko (1969) studied biological activity of soil and his results showed that the addition of organic fertilizers, even in small amounts, increased the evolution of CO_2 from the soil. He concluded that organic fertilizers alone or the mineral fertilizer alone greatly increased the biological activity of the soil as compared with the control. He also found that not only are the microbiological processes involved in converting ammonia nitrogen into nitrate nitrogen during incubation period, but that the content of ammonia nitrogen was continuously replenished as the result of mineralization from the organic matter. The addition of fertilizers had some effect on the ammonification process. Thus, the application of fertilizers intensified the biological activity of soils (greatly intensified CO_2 evolution), and also intensified the nitritication capacity of the soil (except when chloride-containing potassium salts were added).

The large amount of Al in some tropical soils has been proposed as a possible inhibitor of the decomposition of organic matter (Harris, 1963; Kawaguchi and Kyume, 1959). Broadbent, et al. (1964) reported that soils which have a high allophane content were slow in the mineralization of both N and C. Aluminum was postulated to slow decomposition rates, either through strong adsorption of Al on the organic matter, forming stable organo-aluminum complexes, or through toxic effects of Al on microbial activity. Mutatkar and Pritchett (1966) found that the average CO_2 production increased significantly with an increase in soil pH from 4.0 to 6.5 and decreased significantly with increasing amounts of Al added to the soil that had been initially adjusted to pH 4.0. However, at pH 5.5 aluminum had little effect on CO_2 liberation, and at pH 6.5, CO_2 evolution was slightly stimulated by addition of the higher rates of aluminum salt. This increase was probably due to changes in pH during incubation because soil with added aluminum salt was decreased in soil pH, and carbon dioxide production during incubation increased with decrease in pH when soil had been initially adjusted to pH 6.5.

Frederick (1956, 1957) concluded that nitrate formation took place at all temperatures between 2° to 35°C, with the greatest change occurring between 7° and 15°C. The increase in the rate of nitrification with increasing temperature was quite rapid. He also mentioned that the decrease in nitrification after increasing incubation periods may be caused by an increase in acidity as nitrate is formed. Meiklejohn (1953) and Warington (1879) found a similar limited temperature range for nitrification. They reported that optimum

temperature for nitrification of ammonium nitrogen lies between 27° and 35°C, and did not proceed at 40°C.

Although many investigators have noted that mobile nitrogen (NH_4-N + NO_3-N) increased with temperature under laboratory condition, there is no consensus on the reason for this phenomenon. A majority attributes it to the mass death of microorganisms in heated soil; the residue is utilized by the surviving and rapidly multiplying species and forms of microbes which may be more resistant to temperature action (Russel, 1955; Vigorov, 1956; Frantsesson, et al., 1957; Newhall, 1958; Lebedyantsev, 1960). Newhall (1958) assumed that heating the soil killed only non-spore forming bacteria, so ammonifiers which produce spores can survive; therefore, ammonification is intensified, especially in soil high in organic matter.

Aref'yeva and Kolesnikov (1964) found that NH_4-N increases in the litter and humus horizon immediately after the soil is exposed to fire and burning kills a great population of microorganisms which do not grow until sometime later. Therefore, they concluded that increase in the ammonia content of burnt and heated soil cannot be related solely to the vital activity of microorganisms. Khlustikova-Dikusar (1936) contended that high temperature gives rise to chemical changes in heated soils associated with the process of oxidation of organic matter. However, the mechanism of this process has not been elucidated.

Aref'yeva and Kolesnikov (1964) stated:

> In the light of modern ideas on phenomenon of cation exchange, soil ammonium need not be present only in an adsorbed state on the surface of soil colloids (57)[1] and in bacterial

[1]Tullin, A. F. 1958. Organomineral colloids in soil, their genesis and significance for root nutrition of the higher plants. Izd. AN SSSR.

zoogel (8).[2] It may also be found in a nonexchangeable (fixed) state as part of the crystalline lattice of soil minerals or as part of the molecules of organic matter (71,[3] 72,[4] 76,[5] 48[6]). Thus, it is completely unavailable to microorganisms. Temperature actions have been found to change the size of crystalline lattice of soil minerals. It is reasonable to assume that in the process part of the fixed ammonia enters an exchangeable state, increasing its quantity in the soil. The same thing may well happen to ammonia fixed in the molecules of organic matter of heated (scorched) soils.

Waksman, et al. (1939) studied the influence of temperature on composts and reported that 75°C was unfavorable for biological decomposition of organic matter and that only spore forming bacteria were found to be surviving and active. Most of the organisms were dead. The most rapid decomposition of organic matter at the first state occurred at 65°C, followed by that at 50°C. After that, the process was found to proceed more rapidly at 50°C than at 65°C. The microorganism involved in the process at 65°C were mostly bacteria and actinomycetes as fungi appeared only seldom. At 50°C certain thermophylic fungi and actinomycetes were very active and played the predominant role, in addition to the bacteria. At 28°C the decomposition was considerably delayed, but after 9 to 10 days of

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[2]Vigorov, L. I. 1956. Change in amount of mineral nitrogen after electrical heating of soil. Sad i ogorod., No. 12.

[3]Allison, F. E. and E. M. Roller. 1955. Fixation and release of ammonium ions by clay minerals. Soil Sci., Vol. 80.

[4]Boner, C. A. 1950. Fixation of ammonium in difficulty exchangeable form under moist conditions by some semi-arid region soils. Soil Sci., 7019.

[5]Mela, P. 1960. Fixation of ammonium by clay minerals in relation to some probable effects on the vegetative development of plants. Soil Sci., Vol. 93.

[6]Smirnov, P. M. and N. I. Fruktova. 1963. Nonexchangeable fixation of ammonia by soils. Pochvovedeniye, No. 3.

incubation it began to decompose rapidly. This phenomenon is due to a development of an extensive microbiological population, because at the lower temperature a highly heterogenous population of bacteria, fungi, actinomycetes, protozoa and nematodes was found. They also found that nitrification took place only at 28° and 50°C and that very little nitrate was formed at 65°C. The ammonia which resulted from the secondary decomposition process was found to be accumulated.

Waksman and co-workers also state:

> Nitrogen was conserved in the manure only when immediate decomposition set in. This resulted in a rapid breakdown of the carbohydrates and the transformation of the soluble nitrogen into soluble forms. Whenever decomposition was delayed, either because of too low or too high temperature, losses of the volatile forms of nitrogen occurred.

R-Etinger-Talczynaka (1969) investigated the influence of different factors on the nitrification of an added ammonium salt and inherent soil-N in soils from arid and semi-arid areas of Israel and reported that rapid nitrification of NH_4-N occurred at 28°C but was inhibited partially or completely at 37°-40°C. In contrast to this, nitrate formation from inherent soil-N proceeded better at 37°-40°C than at 28°C. Upon an examination of the microbial population, he found that there was an injurious effect on the population of nitrifiers at 37°-40°C, especially the nitrate-forming bacteria. Nitrification by Nitrosomonas and Nitrobactor groups was also inhibited at 37°C, as compared with that at 28°C. He concluded that the great part of nitrate originating from soil-N is produced by some process other than that which is responsible for nitrification of NH_4-N. He also found that autoclave sterilization caused a complete loss of the nitrate-producing property from either soil-N or ammonium-N.

Therefore, it can be assumed that not only the nitrification of ammonium-N but also the nitrification of soil-N is of a biological origin. He discussed that nitrification of NH_4-N does not take place in the soil solution but is connected with those sites of soil samples which are cation-exchangeable, and that nitrifiers do not multiply in the soil solution but in the area of a complex which is formed from ammonium-N and soil particles. So when all sites of this area are fully occupied by the proliferated specific bacteria, no further multiplication takes place unless a fresh quantity of ammonium-N is added.

Russel, et al. (1925) found that nitrate production is comparatively slow at 5°C and nitrate production was increased rapidly with increasing temperature. Thirty-five degrees was the optimum temperature for greatest nitrate production. Above this temperature, nitrification became slower and ceased at 55°C. This conclusion agrees with the observations of Schloesing and Müntz in 1879.

According to Parker and Larson (1962), they mentioned that 2°C difference in temperature at temperatures between 16° and 20°C had a measurable effect on the rate of oxidation of NH_4-N to NO_3-N production from NH_4-N applied to the soil. This difference was about equal at the various temperatures after incubation for 5 weeks. The total amount of NO_3-N produced increased with an increase in temperature; the nitrification of the residual soil-N was temperature dependent and this was the determining factor in the total production of NO_3-N. They presumed that NO_3-N production in the non NH_4-N-treated soils was derived as a result of ammonification of soil

organic matter. At temperature above 20°C, a 2°C difference had less effect on the rate of nitrification, and the NH_4-N applied to the soil material was rapidly oxidized.

Wijler and Delwiche (1954) suggested that alternating aerobic and anaerobic soil conditions resulting from autotrophic consumption of oxygen at low oxygen tensions may result in greater total nitrogen losses than would be found under strict anaerobic conditions. In general nitrification is essentially an aerobic process, but it can occur at an extremely low partial pressure of oxygen where rapid denitrification is known to occur (Amer and Bartholomew, 1951). On the other hand, denitrification is essentially an anaerobic process, but appreciable losses of nitrogen may occur in well-aerated soils (Broadbent, et al., 1952; Wijler, et al., 1954). Under appropriate conditions, nitrate accumulation in soils may be largely dependent upon the extent of volatile nitrogen losses (Clark, et al., 1960). Theoretically, losses will be greater in the absence of oxygen.

Results of Brandt, et al. (1964) showed that in most unamended soils, nitrate initially present declined during the first 2 to 4 weeks of incubation and was replaced almost quantitatively by NH_4^+, and initial nitrate disappeared completely at a moisture content above 50%. And after 20 to 30 days of incubation, nitrate again accumulated in unamended soil. However, accumulation of nitrate was interrupted by recurrent periods of nitrate disappearance. This disappearance was accompanied by relatively smaller increases in NH_4^+. It may be inferred that recurrent periods of nitrate disappearance were associated with periods of enhanced biological demand for oxygen

because changes in oxygen diffusion rate tended to parallel changes in NO_3^-. In contrast, periods of reduced biological demand for oxygen were associated with periods of net ammonification in the amended soil. This would suggest that sharp peaks of NH_4^+ accumulation occurred during periods of autolytic breakdown of microbial tissue during the decline phase of successive climax populations. Brandt also found that mineral nitrogen deficit tended to increase during the later 30 days of incubation at 35°C. It is possible that chemical decomposition of NO_2^- formed during nitrification contributed to losses of nitrogen, and both NO_2^- and NO_3^- were reduced to gaseous products because nitrite accumulated in quantity that was less than equivalent to ammonium disappearance.

Thiagalingam (1967) studied the effect of temperature on nitrification of added ammonium nitrogen and mineralization of native nitrogen in four Hawaiian soils (Paaloa, Wahiawa, Lualualei, and Maile) at temperatures ranging from 5° to 40°C. He reported that the rate of nitrification generally increased with a rise in temperature up to 25°C and mineralization of untreated soil was found to be highest at 40°C. These results agreed with some previous investigators (Waksman, 1939; R-Etinger-Talczynaka, 1969; Russel, et al., 1925).

The influence of mineral salts on the rate of ammonification and nitrification have been previously reported by many investigators (Withers and Fraps, 1900; Lipman, 1902, 1909, 1910, 1912; Lipman, et al., 1911, 1912, 1914; Owen, 1908; Krüger, 1908; Engberding, 1909; Lyon and Bizzell, 1909; Fischer, 1909; Kellerman and Robinson, 1910; Brown, 1911; Lemmermann, 1912; Patterson and Scott, 1912; Kelly, 1912;

Allen and Banezz, 1915 and others). Most of the investigators cited above have mainly studied the effect of lime ($CaCO_3$, $MgCO_3$), especially when applied to acid soils, on the bacterial content and activity of the soil. A majority ascribe it to stimulated ammonification and accelerated nitrification in soil. The influence of chloride salts has been reported by some investigators (Lemmermann, 1912; Patterson and Scott, 1912; Lipman, et al., 1902, 1909, 1910, 1912, 1913; Quastel, et al., 1951; Agarwal, et al., 1967; Singh and Kanehiro, 1968; Greaves, 1916; Pathak and Jain, 1965; Brown and Hitchcock, 1917; Johnson and Guenzi, 1963). Their results showed that there was a distinct decrease in nitrate production as application of NaCl was increased.

Lipman (1902) showed that when 0.1 percent of NaCl was added to the soil, nitrification was greatly diminished. Later in 1909 and 1910, he reported that the chlorides of Ca, Mg, K, and Na were found to be toxic in the order named, and that $CaCl_2$ in solution accelerated the activity of ammonifiers. Lemmermann (1912) found that $CaCl_2$ and $MgCl_2$ reduced the loss of ammonia and KCl and NaCl both reduced the adsorption power of the soil. Patterson (1912) similarly found that NaCl had a distinctly injurious effect on nitrification. McBeth and Wrigh (1912) found that carbonates, chlorides and sulphates inhibited nitrification in the order of decreasing effect. Lipman (1912) demonstrated that ammonification is inhibited by NaCl, Na_2SO_4 and Na_2CO_3 and the point at which NaCl becomes toxic to ammonification was between 0.1 and 0.2%, and the point at which NaCl was toxic to nitrifier was less than 0.1%. Lipman and Sharp (1912) also found the point at which NaCl becomes toxic to nitrogen-fixing organisms in soil to be

from 0.5 to 0.6%.

Greaves (1916) mentioned that at times the stimulating effect, or even the toxic influence, may be due to the liberation of a substance within the molecule of the salt that was toxic to the microorganisms; as in the case of sulphate, it may be the sulphur. He studied the influence of chloride salts in 1916 and found that all of the chlorides tested, except $CaCl_2$ and KCl, increased the accumulation of ammonia in the soil and the extent of stimulation was governed largely by the cation, while the toxicity of the compound is governed by the anion. The order of most effective to least stimulation to ammonifying organisms is $FeCl_3$, NaCl, $MgCl_2$, $MnCl_2$. The last two stimulated only slightly. Later in 1919 Greaves and co-workers established a similar series in order of decreasing toxicity to nitrifiers as KCl, $MgCl_2$, $FeCl_3$, $CaCl_2$. Apparently, the results showed that the compounds that have higher atomic weights of cation are greater stimulators than those with lower atomic weights, and toxicity of active stimulants increased more rapidly than inactive stimulants when increasing concentrations of salt were added. Furthermore, increased osmotic pressure exerted by increasing concentration of salt added to the soil played an important role in the retardation of bacterial activity. However, it is not the only factor; the main factor is probably due to a physiological change which affects action of a particular mineral salt upon the living protoplasm of the cell, changing its chemical and physical properties so that it cannot function normally.

Agarwal (1967) studied the effect of chloride and sulphate salts on available nitrogen release from some Hawaiian soils. He listed a

series of salts in decreasing order of causing nitrogen release as follows: $CaCl_2$, KCl, NaCl, K_2SO_4, Na_2SO_4, $CaSO_4$. Singh, et al. (1968) considered that the order of decreasing NH_4-replacing power was Al > Fe > Ca > Mg > K > Na, when the anion (Cl^-) was kept constant to avoid complications due to anionic effect and to get an insight of only the cationic effect. They also found out that the amounts of CO_2 evolved from the sample treated with chloride salts were lower than in the control and hence concluded that the addition of chloride salts had little or no stimulative effect on the microbial activity in the soil. Both cation as well as anion species are involved in effecting NH_4-N release from the organo-inorganic complex in the soil and the magnitude of release generally increased with successive increments in salt concentration.

MATERIALS AND METHODS

Description of Soil Used

The Hawaiian soil used in this investigation was collected from the Kaiwiki Forest Reserve of the Hilo Coast, Island of Hawaii. It belongs to the Akaka series, which was formerly classified as a Hydrol Humic Latosol in 1955 and now has been classified to a Typic Hydrandept, according to the Comprehensive Classification System of 1968. The yellowish-red Akaka soil is derived from volcanic (basaltic) ash. It occurs at altitudes of 800 to 6000 feet on the windward side of the islands of Hawaii and Maui and has developed under high rainfall that ranges from 120 to 300 inches per year (Cline, 1955). The uncultivated soil has a distinct surface accumulation of organic debris and numerous roots which make the soil soft, wet and mushy. It is extremely acid (pH about 4.4 to 4.8) and has a high cation exchange capacity (CEC) of about 80 to 100 me/100 g. soil, and a low base saturation (BS) of about 2% (Kanehiro and Chang, 1956). The soil is characterized by a field moisture of about 190-220%, a moisture equivalent at 1/3 bar about 145-150%, at 15 bar about 80-84%. It also has a high water holding capacity, rapid infiltration rate, moderately good drainage, and a slow run-off. Akaka soil is extensively mapped, and large acreages of this soil are devoted to sugar cane and pasture use. The mineralogical composition of the clay fraction is largely allophane and hydrated iron-aluminum oxides, with no kaolin minerals. This soil dries irreversibly and contains high amounts of organic carbon (14.6%) and total nitrogen (0.8%) on a dry-weight basis (Singh, Agarwal and Kanehiro, 1969).

Preparation of Soil Sample

Uncultivated surface soil to a depth of 6 inches was collected from the aforementioned site, placed in double plastic bags, and tied tightly with string to avoid moisture loss from the soil during delivery and storage periods. The sieved soil sample, before use, was stored in secured double polyethylene bags and kept in a refrigerator to hold changes in soil property at a minimum. The moisture content, NH_4-N and NO_3-N present in the soil were determined before experimentation.

Experimental Procedures

Experiment I. Effect of Different Concentrations of Chloride Salts on Available Nitrogen and Carbon Dioxide Release in Akaka Soil at Room Temperature.

The influence of different concentration of sodium, calcium, and aluminum chlorides on NH_4-, NO_3-N, and CO_2 release was studied. Twenty five grams of soil (on oven-dry basis) were placed in a 500 ml Erlenmayer flasks. The calculated amounts of the three chloride salts were added to the soil in the flask and mixed well. The water content of the soil when sampled was slightly greater than its moisture equivalent, so no additional water was added before mixing. The salts were added to give molar concentrations of 0.0, 0.1, 0.3, 0.5, 0.7, 1.0, and 2.0 M. In the same flask, a vial containing 1 N NaOH was suspended from a rubber stopper used to stopper the flask. This was to absorb CO_2 which was liberated from the soil. The mouth of the flask was tightly capped with polyethylene film to prevent escape of CO_2 and soil moisture. The samples were incubated at room temperature for

periods of 7, 14, 21, and 28 days. At the end of these periods, samples were analyzed for NH_4- and NO_3-N. Carbon dioxide analysis were carried out once a week for all treatments and a fresh supply of NaOH was placed in the vial after each CO_2 analysis. This was done to allow for weekly aeration of the flask. The treatments were carried out in duplicate.

Experiment II. Effect of Different Concentrations of Chloride Salts on Available Nitrogen and Carbon Dioxide Release at Different Temperatures.

The study of the influence of different salt concentrations of sodium, calcium, and aluminum chlorides on available nitrogen and CO_2 release at three temperatures was carried out as described in Experiment I, with the following differences:

a. The salt concentrations were limited to 0.0, 0.001, 0.01, 0.1, and 1.0 M, and

b. The temperatures of incubation were set at 30°, 45°, and 65°C.

Experiment III. Effect of Sterilization on Available Nitrogen and Carbon Dioxide Release in Akaka Soil with Different Concentrations of Sodium Chloride at Room Temperature.

To study the effect of NaCl on NH_4-N and NO_3-N and CO_2 release in sterile Akaka soil, 25 g. of sieved soil (on oven-dry weight basis) were placed into a 500 ml. Erlenmayer flask. The flask was covered with aluminum foil to avoid soil moisture loss during sterilization.

The soils were autoclaved at a steam pressure of 15 lbs/inch^2 and at a temperature 220°C for one hour. When the soil had cooled down after sterilization, NaCl was added to give molar concentrations of 0.0, 0.001, 0.01, 0.1, and 1.0 M. The samples were subsequently incubated in the manner as described for Experiment I, and then analyzed for NH_4- and NO_3-N and CO_2. An analysis was also carried out immediately after the soil was sterilized and before any NaCl was added, to determine the status of NH_4- and NO_3-N. The treatments were carried out in duplicate. The equipments and glasswares were sterilized before use to prevent microbial contamination.

Analytical Procedures

Determination of NH_4-N and NO_3-N

In these experiments the 25 g. of soil contained in a 500 ml Erlenmayer flask was extracted with 250 ml 2 N KCl solution on a reciprocating shaker for one hour and filtered through a Whatman folded filter paper No. 2^V. Sufficient filtrate (about 100-150 ml) was collected for analysis and kept in refrigerator until analyzed. Only NH_4-N and NO_3-N were determined for available nitrogen because NO_2-N was not present in sufficient amounts to warrant its determination. At any rate, any available NO_2-N was destroyed by addition of 1 ml of 2% sulfamic acid to soil extract prior to NH_4-N analysis.

Ten milliliters of soil extract were pipetted into a distillation flask of micro-Kjeldahl steam distillation apparatus. Nitrite nitrogen was destroyed by swirling the aliquot for a few seconds with 1 ml of 2% sulfamic acid. Two grams of MgO, previously heated at 600 to 700°C for 2 hours in muffle furnace, were added to the bottom of flask with

caution. Steam was added into the flask immediately by connecting the flask to the steam distillation apparatus. Thirty milliliters of distillate were trapped with 5 ml of 2% boric acid-indicator solution in a 50 ml receiving Erlenmayer flask. The rate of steam generation was adjusted to collect the distillate at a rate of 7 to 8 ml per minute. The distillate was determined for NH_4-N by titration with standard 0.005 N H_2SO_4. The color change at the end point was from green to a permanent faint pink.

After removal of NH_4-N, NO_3-N was determined on the same extract by addition of 0.2 g of Devarda's alloy to the distillation flask and distilling in the same manner described for NH_4-N.

Calculation of the Amount of Nitrogen Present

a. Titration value = (ml of H_2SO_4 used in sample) - (ml of H_2SO_4 used in blank)

b. meq of nitrogen = titration value (a) x normality of H_2SO_4

c. ppm of nitrogen = meq of nitrogen (b) x 14

Determination of CO_2 Evolution

Carbon dioxide is one of the principle products of the heterotrophic microorganisms and its evolution from the soil has frequently been used as a measurement of microbial activity (Waksman and Starkey, 1924). For this investigation, CO_2 was measured by the titrimetry method because it is used universally and is well adapted to soil investigations. The procedure used was that of Pramer and Schmidt (1964) and Moodie (1961) which consists of placing 25 g of soil (oven dry basis) into a 500 ml Erlenmayer flask. The flask was

rubber-stoppered with a vial, containing excess amount of 1 N NaOH to absorb of evolved CO_2, hung from the stopper. The stopper was kept tightened during incubation to prevent CO_2 and moisture loss, especially when the temperature of incubation was high. After incubation at various periods, the amount of CO_2 evolved was determined by transferring the NaOH from the vial into a 125 ml Erlenmayer flask, rinsing the vial several times with CO_2-free distilled water to ensure complete transfer of NaOH to the flask, adding excess amount of 1 N $BaCl_2$ (about 10 ml of $BaCl_2$/5 ml of NaOH used) to precipitate carbonate (Na_2CO_3), and titrating the left-over NaOH with standard 0.5 N HCl, using phenolphthalein as the indicator.

The chemical reactions providing the basis of this method are as follows:

a. $2\ NaOH + CO_2 = Na_2CO_3 + H_2O$

b. $Na_2CO_3 + BaCl_2 = BaCO_3 + 2\ NaCl$

c. $NaOH + HCl = NaCl + H_2O$

The result expressed as mg of C/25 g soil.

Calculation of the Amount of CO_2 Evolution

$$\text{mg of C} = (B - V) \times NE$$

where B = volume (ml) of HCl used to titrate NaOH in the CO_2 collected from blank.

V = volume (ml) of HCl used to titrate NaOH in the CO_2 collected from soil sample.

N = normality of HCl

E = equivalent weight of C = 6

Statistical Analysis

Statistical analysis was carried out on IBM 360-computer at the University of Hawaii Computing Center. The factorial split plot analysis program from the Computing Center of Pennsylvania State University was used for analysis of variance, and means were tested with the Duncans Multiple Range Test using Harter's Critical Values.

RESULTS

Experiment I. Effect of Different Concentrations of Chloride Salts on Available Nitrogen and Carbon Dioxide Release in Akaka Soil at Room Temperature.

1. Effect on NH_4-N Release

The amounts of NH_4-N (ppm) released in the Akaka soil as affected by different concentrations of chloride salts at room temperature are given in Table I and illustrated in Figure 1; the analysis of variance is given in Table III.

The time of incubation, concentration and the kind of cation and their interactions were all found to have a highly significant influence on the amount of NH_4-N release (Table III). The amount of NH_4-N released was directly related to period of incubation; large cumulative ammonium release values were generally found with long incubation periods (Table I). When NaCl and $AlCl_3$ were added to the soil, the amount of NH_4-N accumulated increased directly with increasing time of incubation; but in $CaCl_2$-treated soil, the amount of NH_4-N increased with time up to 3 weeks of incubation, then decreased slightly during the last week of incubation (Appendix Table I).

The amount of NH_4-N accumulated generally increased when concentration of chloride salts was increased (Fig. 1a, 1b, and 1c). However, there was a maximum concentration for each salt beyond which the amount of NH_4-N release decreased with increasing salt concentration. These concentrations were 1.0 M for NaCl, 0.7 M for $CaCl_2$, and 0.1 M for $AlCl_3$ (as shown in Fig. 1a, 1b, and 1c,

respectively), except in the last 2 weeks of incubation in $AlCl_3$-treated soils, where the amount of NH_4-N release was substantially higher at 0.3 M than at 0.1 M concentration. Furthermore, when $AlCl_3$ was added to the soil at concentrations greater than 0.5 M, NH_4-N release values became negative since they were lower than the control value (Fig. 1c).

The cation valence also showed a highly significant influence on NH_4-N release. Generally, all chloride salts stimulated NH_4-N release in the soil. The order of increasing stimulation was $AlCl_3$, NaCl, and $CaCl_2$. $AlCl_3$ became toxic to the ammonification process at concentrations higher than 0.5 M (Fig. 1c).

2. Effect on NO_3-N Release

The effect of different concentrations of chloride salts on NO_3-N release is shown in Table I; the analysis of variance is given in Table III. The magnitude of NO_3-N increase was very small; however, time of incubation, concentration and cation valence played important roles in this process, as shown by the amount of NO_3-N liberated in Table I, and their interaction in the analysis of variance in Table III. The factors which had significant influence on NO_3-N release were found to be in the same order as those which influenced NH_4-N release, that is, time of incubation, concentration, and cation of chloride salts, respectively (Table III). In general, nitrification was inhibited at concentration of chloride salts of 0.5 M or greater. Nitrifying bacteria seemed to be inhibited by NaCl in the first two weeks of incubation. Stimulated in the third week and either inhibited or stimulated slightly during the fourth week, depending on salt concentration. A close examination of Table I shows that there was a

general increase in NO_3-N in NaCl-treated soils. The NO_3-N release pattern for $CaCl_2$- and $AlCl_3$-treated soils did not show as much consistency than that of the NaCl treated. The $CaCl_2$-treated soils generally showed an "up and down" pattern through the periods of incubation when concentration of salt used increased up to 0.5 M. Beyond this concentration, the amount of NO_3-N increased up to the second week of incubation, then dropped down at the third week and rose up again at the last week. In $AlCl_3$-treated soils, low levels of concentration (below 0.7 M) showed little or no effect on NO_3-N release as compared to the control. But at concentrations higher than 0.7 M, the results generally showed stimulation of nitrification in the first 3 weeks of incubation. A decrease in nitrate values, excepting for the 2.0 M concentration, occurred in the fourth week.

Hence, when different chloride salts were added to the soil, the amount of NO_3-N release was slightly differed for each salt used. With the same salt, when different concentrations were used, in most cases there was no significant difference (Table I). According to this test, the difference in pattern of NO_3-N release was due mainly to the cation in the chloride salt.

3. Effect on CO_2 Release

The effect of different concentrations of chloride salts on CO_2 release is shown in Table II and illustrated in Figure 2. The analysis of variance is given in Table III. The amounts of CO_2 evolved shown in Table II are the amounts of CO_2 released per week, and these amounts were used to obtain the cumulative amounts of CO_2 release at different periods shown in Figure 2.

The results showed that the cumulative CO_2 evolved in the Akaka soil was directly related to the amount of NH_4-N release, where different concentrations of chloride salts were added to the soils (as shown in Fig. 1 and 2). The related stimulating effect of chloride salts on CO_2 liberation and on NH_4-N release was noticeable in both $CaCl_2$- and $AlCl_3$-treated soils, but not in NaCl-treated soils. As pointed out earlier, NH_4-N release was stimulated by all concentrations of NaCl, with the maximum concentration being 1.0 M. With CO_2 release, all concentrations of NaCl (excepting 1.0 M) resulted in lower CO_2 values than the control, with the 2.0 M treatment showing the lowest values (Fig. 2a).

A study of the analysis of variance in Table III shows that the cation had the greatest influence on CO_2 liberation, followed by time of incubation and salt concentration in decreasing order of influence. Carbon dioxide liberation in salt-treated soils was generally very active only in the first week of incubation (see Table II). After this it dropped sharply in the second week and declined slightly in the third and fourth weeks. The amount of CO_2 released from the soil generally increased when salt concentration was increased but only to a certain maximum. As with NH_4-N release, the optimum salt concentrations for effecting CO_2 release were as follows: 1.0 M for NaCl, 0.7 M for $CaCl_2$, 0.1 M for $AlCl_3$. Beyond these concentrations, the amount of CO_2 released declined with an increasing salt concentration (Fig. 2).

Experiment II. Effect of Different Concentrations of Chloride Salts on Available Nitrogen and Carbon Dioxide Release in Akaka Soil at Different Temperatures.

1. Effect on NH_4-N Release

The results of the effect of different concentrations of chloride salts on NH_4-N released are shown in Tables IV, V, and VI, and illustrated in Figures 3, 4, and 5; the analysis of variance is given in Table VII.

Temperature showed the highest significance on the effect of chloride salts on NH_4-N released in the soil, followed by time of incubation, concentration and cation of chloride salts used, in order of decreasing ratios, respectively (Table VII). The amount of NH_4-N accumulated in the soil generally increased with temperature and time of incubation, and increased with increasing concentration up to 0.1 M of chloride salts used; at higher concentration beyond this point (1.0 M), the amount of NH_4-N released decreased. Cation valence of chloride salts showed different effects on NH_4-N released, depending upon temperature. In NaCl-treated soils, a slight stimulating effect on NH_4-N release occurred at 65°C, moderate at 45°C, and highest stimulating effect occurred at 30°C. These are in comparison with the control treatment.

As mentioned above, stimulating effect at each temperature has its own limited concentration of salt added. In NaCl-treated soils, at 30°C, the amount of NH_4-N released increased with increasing salt concentration and time of incubation; however at the end of the fourth week, NH_4-N release had levelled off or even decreased

(Fig. 3a). At 45°C, the amount of NH_4-N accumulation increased with increasing salt concentration up to 0.1 M but decreased when higher concentrations of salt (1.0 M) were added. Amount of NH_4-N released increased with time of incubation (Fig. 4a). At 65°C, the amount of NH_4-N released decreased with increasing salt concentration and increased with increasing time of incubation (Fig. 5a).

When $CaCl_2$ was added to the soil, the amount of NH_4-N released generally increased with time of incubation, with a few exceptions, such as the decline in the second week of incubation at 30°C (Fig. 3b). At this temperature, rate of NH_4-N liberation was increased with increasing salt concentration. Calcium chloride treatments showed increasing NH_4-N release with increasing salt concentrations at 30°C.

When the temperature was raised to 45°C, increasing the concentration of salts up to 0.1 M caused an increase in the amount of NH_4-N in the $CaCl_2$-treated soils; however, ammonification was retarded by the highest molar concentration of 1.0 (Fig. 4b). Ammonium nitrogen released in $CaCl_2$-treated soils at 45°C was generally lower than in the control soil. The lowest release was obtained at highest concentration of 1.0 M, and amount of NH_4-N released also fluctuated with time.

In $CaCl_2$-treated soil, incubated at 65°C, concentration did not show much difference in amount of NH_4-N released, and ammonification was retarded when soil was amended with $CaCl_2$ (Fig. 5b).

The amount of NH_4-N released from $AlCl_3$-treated soil, incubated at 30° and 45°C, increased with increasing concentration up

to 0.1 M. The amount released dropped very sharply when the concentration was above 0.1 M (Fig. 3c and 4c). At a molar concentration 1.0, amount of NH_4-N accumulated in soil was just about half of that with other treatment. At 65°C, released value of NH_4-N kept increased with increasing concentration. Ammonium nitrogen accumulated in soil was about the same amount for the concentration below 1.0 M (Fig. 5c). Aluminum chloride showed a stimulating effect on ammonification at concentration 1.0 when soil incubated at 65°C, but showed a toxical effect at 30° and 45°C.

2. Effect on NO_3-N Release

Data obtained on the effect of chloride salts at different concentrations on NO_3-N released at different temperatures are shown in Tables IV, V and VI; analysis of variance is included in Table VIII.

As the statistical analysis shows in Table VIII, temperature was the most important factor that affected the amount of NO_3-N released from the soil. Cation valence, time of incubation, and concentration of salt used were found to be in order of decreasing significant influence on NO_3-N released in the soil. The NO_3-N release values generally increased with increasing temperature and decreased with increasing order of atomic valence of chloride salts sued; these increases and decreases fluctuated with periods of incubation and concentrations of salt. The pattern on the effect of incubation period was an "up-and-down" one, while effect of concentration was a "down-and-up" one.

When NaCl was added to the soil at 30°C, NO_3-N data showed mostly negative figures at all periods of incubation. At 45°C and

65°C the negative figures were limited to only the fourth week of incubation (Table IV). The results also show evidence that there are NO_3-N losses during the first two weeks of incubation at all levels of temperature with $CaCl_2$ and $AlCl_3$ additions (Tables V and VI). At the last two weeks of incubation, however, this trend was reversed and there were generally more gains than losses of NO_3-N. Salt concentration influence on NO_3-N release occurred only when soil was incubated at 30°C. At other temperature levels not much difference in amounts of NO_3-N release occurred.

3. Effect on CO_2 Release

The results including the amount of CO_2 evolved with chloride salt addition to the soil at different temperatures and the statistical analysis of this study are shown in Tables IX, X, XI, and XII, and illustrated in Figures 6, 7, and 8. Tables IX, X, and XI show the individual amounts of CO_2 evolved at a given period of incubation, while the amounts of CO_2 accumulated at a given time are illustrated in Figures 6, 7, and 8.

The analysis of variance in Table XII shows that temperature was the most important factor affecting CO_2 evolution in the soil. Other highly significant factors were time of incubation, cation valence of chloride salt, and salt concentration, presented here in a decreasing order of F ratios. Amount of CO_2 release generally increased with increasing temperature and decreased with period of incubation (Tables IX, X, and XI). There was generally greatest CO_2 release with $AlCl_3$ addition, followed by NaCl and $CaCl_2$ additions, respectively. In most cases, increasing salt concentration gave

decreasing CO_2 evolution, and at the molar concentration of 1.0, the amount of CO_2 liberated in soil was nearly always lower than that liberated from the control treatment (Fig. 6, 7, and 8). The microbial activity in the soil (as reflected by CO_2 evolution) was most active at the first week of incubation, then declined sharply at the second week and maintained nearly this same activity when the incubation period was carried longer than two weeks. In most cases, a little decline in the amount of CO_2 evolved was shown at the last week.

Experiment III. Effect of Sterilization on Available Nitrogen and CO_2 Release in Akaka Soil with Different Concentrations of NaCl at Room Temperature.

1. Effect on NH_4-N Release

The data on the amount of NH_4-N released in sterile Akaka soil as affected by NaCl and its statistical analysis are shown in Tables XIII and XV, and illustrated in Figure 9a.

As shown by the analysis of variance in Table XV, concentration of NaCl and time of incubation had a highly significant effect on NH_4-N release in sterile Akaka soil. This experiment shows that even in a system free of microorganisms, NH_4-N was still released from soil, and the amount differed with the concentrations of sodium chloride (Table XIII). Amount of NH_4-N released increased with concentration up to 0.1 M. At concentration of NaCl added was greater than 0.1 M, the amount of NH_4-N released showed a negative figure at the first two weeks and this lowered trend of ammonification was the same for the other concentrations of NaCl added. The chemical reaction on NH_4-N release was very active only in the first week of the incubation period;

after one week, NH_4-N values dropped down and stayed down or slightly increased when incubation period was carried longer (Table XIII and Appendix Table III).

2. Effect on NO_3-N Release

Amount of NO_3-N released in sterile Akaka soil as affected by different concentrations of added sodium chloride salt and its analysis of variance are included in Tables XIII and XV.

When sterile soil was incubated for a long period, there was evidence that some NO_3-N was lost, the amount of the loss increased with time of incubation. The greatest loss occurred in the three week incubation period; there was a slight increase at the fourth week (Table XIII and Appendix Table III). Some NO_3-N was accumulated in the soil only when the concentration of NaCl did not exceed 0.1 M. This accumulation was evident only in the first week of incubation, after which time NO_3-N value decreased. Although effect of concentration was not shown to be significant (Table XV), it appears from the data in Table XIII that salt concentration was important in determining NO_3-N release in the first week.

3. Effect on CO_2 Release

The data for the effect of NaCl on CO_2 release are shown in Table XIV and XV, and illustrated in Figure 9b. The amount of CO_2 evolved shown in Table XIV is the individual amount of CO_2 released at a certain period and the amount of CO_2 evolution illustrated in Figure 9b is the amount of cumulative CO_2 evolved at a given period of time.

The results show that the cumulative CO_2 released in sterile soil increased with time of incubation and decreased with increasing salt concentrations (Fig. 9b). The chemical reaction on CO_2 release was very active only in the first week of incubation; after this, it dropped down and maintained this same low level until the period of incubation was up.

DISCUSSION

From the results of the studies on the effect of different concentrations of chloride salts at different temperatures and their interactions on available nitrogen and carbon dioxide release in Akaka soil, one can conclude that all factors studied in this investigation, temperature, cation valence, concentration of chloride salts, time of incubation, and sterilization, played highly significant roles in either enhancing or inhibiting nitrogen transformation and CO_2 evolution in this soil. The effect of these factors on available nitrogen and CO_2 release is mainly due to their effect on microbial activities in soil.

Among the factors studied, temperature is one of the most important factors that stimulate nitrogen mineralization and the formation of CO_2 (Appendix Tables IV and V). The amount of CO_2 liberation increased with temperature. The results show that CO_2 evolution took place at any level of temperature up to the highest level conducted in this investigation (65°C), even in sterile soils. This noticeably agrees with previous investigations reported by Déhérain and Démoussy (1896), and Severin (1910-1912). The increase in the amount of CO_2 liberation caused by increasing temperature was due almost entirely to the effect of temperature on organic matter decomposition, either with chemical or biological activities. This explanation was supported by Sollny (1880), Kiszling and Fleischer (1891), Déhérain and Démoussy (1896), Severin (1910-1912), Lundergårdh (1927), Stoklasa (1912), Gainey (1919), Neller (1918), Artyushenko (1969). The amount of cumulative CO_2 release tended to be proportional to the amount of

available nitrogen release (Appendix Tables IV and V). And the intensity of CO_2 production was found to be very great at the beginning of an incubation experiment and decreased rapidly after a short while as shown in Tables II, IX, X, XI, and XIV. Similar results were reported early by van Suchtelen (1910).

The phenomenon that CO_2 evolution was found to be very active only at the early periods might be due to oxygen limitation in a CO_2 evolution system at prolonged incubation periods. Partial anaerobic conditions occurred during the incubation period when the flask containing soil sample was kept tightened to prevent CO_2 escape. Therefore, aerobic microorganism populations were decreased. This might be the reason why the intensity of carbon dioxide release was high only at the early period of incubation and decreased later on.

Ammonification was significantly enhanced with increasing soil temperature (Appendix Table IV). This increase in NH_4-N accumulation with increased temperature might be due to many reasons, but there is no consensus for this phenomenon. A majority of investigators, Russel, 1955; Vigorov, 1956; Frantsesson, et al., 1957; Newhall, 1958; Lebedyantsev, 1960, ascribed the phenomenon of increased NH_4-N with increased temperature to the mass death of microorganisms in the heated soil; the residue of death cells is assimilated by the surviving and rapidly multiplying organisms and probably form microbe species which have more resistance to temperature elevation. Generally at high temperature levels beyond 40°-45°C, only spore-forming bacteria survive, and ammonifying bacteria are the ones that can form spores when heated; therefore, ammonification is intensified, especially in

soil high in organic matter.

Another reason is probably due to the number of organisms in the soil. Waksman, et al. (1939) found that the population of micro-organisms in the soil decreased with an increase in temperature. At room temperature (28°C) a highly heterogenous population of bacteria, fungi, actinomycetes, protozoa and nematode was found. At 50°C, only certain thermophylic fungi and actinomycetes were found to be active, in addition to thermophylic bacteria which played the predominant role on microbial activities. At 65°C only bacteria and actinomycetes were found. Gainey (1919) observed that for every unit of carbon assimilated by microorganism, there is a definite amount of nitrogen assimilated. Neller (1918) also showed evidence that when organic matter in soil contained more nitrogen than organisms need for metabolism, a part of the nitrogen will be left as a waste-product in the form of ammonia. According to these reports cited above, it can be assumed that heating will have a killing effect on many microorganisms and this effect will be increased with increasing temperature. The result will be for NH_4-N to accumulate in soil due to a decrease in population that utilize nitrogen in soil.

A modern idea was ascribed by Aref'yeva and Kolesnikov (1964) who reported that NH_4-N increased with an increase in temperature due to cation exchange caused by temperature action on changing the size of the crystalline lattice of soil minerals. Heating will cause part of the fixed ammonia to enter an exchangeable state, thus increasing its quantity in the soil. Beside the aforementioned reasons, high temperature gives rise to chemical changes in soil which are associated

with the process of oxidation of organic matter in soil (Khlustikova-Dikusav, 1936).

Nitrate accumulation increased with increasing temperature but at 30°C the results showed evidence of NO_3-N disappearance (Appendix Table II); this loss did not occur at room temperature (28°C). This result does not agree with the earlier reports of Waksman (1939), R-Etinger-Talczynaka (1969), Russel, et al. (1925), Schloesing and Müntz (1879), Thiagalingam (1967), Keikliohn (1954), Warington (1879) and Frederick (1956, 1957). These investigators concluded that nitrate formation took place at all temperature up to 40°C and the optimum temperature for nitrification of ammonia nitrogen lies between 27° and 35°C. Above this temperature, nitrification becomes slower and ceases at 55°C. But Waksman (1939) found that at 65°C some very small amounts of nitrate still accumulated in soil. These investigations mentioned above were carried mostly on unamended soil. The result of this study showed that the amount of nitrate accumulated in the soil increased with temperature but the pattern of NO_3-N release showed a fluctuation of nitrification; this fluctuation depends upon the kinds of salt used, concentration and time of incubation. According to this study one can presume that NO_3-N increased when temperature was increased, was not only due to temperature alone but also involved the interaction between temperature and other factors, such as concentration, cation valence of chloride salts, time of incubation, and other factors which need more extensive studies.

Cation valence and concentration of salt added also showed a highly significant influence on values of available nitrogen and CO_2

production but there was no definite or conclusive trend of available nitrogen and CO_2 release in salt-treated soils because the amount of release depends on some other factors involved. The amount of soil nitrogen and CO_2 liberated in a salt-treated soil at different concentrations will be increased or decreased depending on temperature and time of incubation. In general rate of mineralization of N and C increased with increasing concentration and cation valence of salt added. Each salt had its own optimum concentration to enhance the amount of products released. At room temperature (Experiment I), the results showed that the optimum concentration for ammonification and CO_2 evolution was 1.0 M for NaCl-treated soil, 0.7 M for $CaCl_2$-treated soil, and 0.1 M for $AlCl_3$-treated soil, except during the last two weeks of incubation when the amount of NH_4-N release in $AlCl_3$-treated soils was substantially lower at 0.1 than at 0.3 M concentration (Fig. 1 and 2). The optimum concentration for nitrification was lower than that for ammonification and CO_2 evolution; for NaCl-treated soils, it was 0.3 M, for $CaCl_2$- and $AlCl_3$-treated soils, it was 0.1 M. A close examination of the data of Appendix Table VI shows that the difference in optimum concentration of each chloride salt is due mainly to the osmotic pressure in the soil.

The osmotic pressure values at optimum concentrations of each process of ammonification, nitrification and CO_2 evolution in NaCl- and $CaCl_2$-treated soils are either very close or exactly the same, but in $AlCl_3$-treated soils, all processes occurred at the same value of osmotic pressure. According to this, it might be presumed that the effect of salt on soil nitrogen and CO_2 release will be increased or

decreased, depending upon the osmotic pressure in the soil. The optimum osmotic pressure for ammonification and CO_2 liberation in NaCl and $CaCl_2$-treated soils was about 50 atm and about 10 atm for $AlCl_3$-treated soils. For nitrification in all salt-treated soils, the optimum osmotic pressure will be around 7-10 atm. Beyond this optimum osmotic pressure range, the amount of production release will be decreased. Broadbent (1964) and Greave (1916) reported that osmotic pressure played a very important role on protoplasm breakdown of microorganism cell, more salt added meant more injury to microorganisms because an increase in concentration of salt added will increase osmotic pressure, and too high an osmotic pressure beyond an optimum point will cause protoplasm breakdown. This helps to explain why the addition of concentrations of salts beyond the optimum point will cause a decrease in amount of soil nitrogen and CO_2 release.

The phenomenon of increased or decreased available nitrogen and CO_2 release is hence probably due to a stimulating or toxical effect of salts and concentration of salts on microbial activities in soil which might be caused through (1) the liberation of a substance from salt that was toxic to the microorganism, as in the case of sulphate, it may be sulphur, (2) an increase of osmotic pressure with increased salt concentration that played an important role in the retardation of bacterial activity as aforementioned, (3) the action of salt upon the living protoplasm of cells, changing their chemical and physical properties so that they cannot function normally. This abnormal function might be caused by the penetration of a particular mineral through the cell membrane and subsequent accumulation in the protoplasm

of microorganisms (Greave, 1961; Lemmermann and Fresenius, 1912; Paterson and Scott, 1912; Lipman, 1910, 1912). (4) A change in the soil organo-inorganic complex by the effect of cation and anion species; for example, the extent of stimulation on NH_4-N release is governed largely by cation, while the toxicity of the compound is determined by anion (Greave, 1961; Agarwal, 1967). Apparently the compound with the higher cation valence are greater stimulators than those with lower cation valence. Furthermore, those compounds which in dilute solution act as stimulators, will in more concentrated solution increase more rapidly in toxicity than do compounds which are not as active stimulators (Fig. 1 and Appendix Table VI). (5) Change in soil reaction caused by particular acidic and basic cations and anion accumulated in the soil; for example, Al^{+3}, NO_3^-, SO_4^{-2}, will cause an increase in acidity, whereas Ca^{+2}, Mg^{+2}, and NH_4^+ will cause a decrease in acidity. A change of pH will have a great effect on the tolerance of microorganisms (Harris, 1963; Kawaguchi and Kyume, 1959; Broadbent, et al., 1964; Mutatka and Pritchatt, 1966; Frederick, 1956, 1957).

In a system free of microorganisms (sterile soil), small amounts of NH_4-N and CO_2 were still liberated. This phenomenon was previously reported by Severin (1910, 1912). Certainly, production of NH_4-N and CO_2 release in sterile soil was not due to biological activities in the soil but probably due to chemical activities in organic matter breakdown. However, the mechanism of this process has not been elucidated. The magnitudes of the products released in sterile soil, caused by chemical activities were distinctly less than those released in non-sterile soil at the same concentration of the same salt added

(Tables I, II, XIII, and XIV and Fig. 9). Nitrification not only completely ceased when soil was sterilized in an autoclave but also loss of nitrate nitrogen occurred which might be in the form of volatile gas. Therefore, it can be surmised that both nitrogen transformation and carbon dioxide evolution are mainly of biolcgical origin (R-Etinger-Talczynaka, 1969; Artyushenko, 1969; avn Suchtelen, 1910; Russell and Appleyard, 1915; Gainey, 1919; Neller, 1918; Déhérain and Démoussy, 1896; Landegårdh, 1924; and Waksman, 1939).

SUMMARY AND CONCLUSIONS

Studies on the effect of different concentrations of chloride salts and temperature on available nitrogen and CO_2 release were conducted with an amorphous Hawaiian soil belonging to the Akaka series. Firstly, an experiment was begun to study the narrow range of salt concentration that affects the amount of available nitrogen and CO_2 release in Akaka soil. Concentrations of NaCl, $CaCl_2$, and $AlCl_3$ ranging from 0.0, 0.1, 0.3, 0.5, 0.7, 1.0, and 2.0 molar were added to the soil and incubated at room temperature.

The results of this first experiment showed that the magnitude of available nitrogen and CO_2 release started to decrease in NaCl-treated soil at a concentration beyond 1.0 M, in $CaCl_2$-treated soil at 0.7 M, and in $AlCl_3$-treated soil at 0.1 M. An exception was at the first two weeks of incubation when NH_4-N release in $AlCl_3$-treated soil was substantially higher at 0.3 M than at 0.1 M concentration. Based on this and previous results it can be concluded that at room temperature, when soils are amended with chloride salts, the amount of available nitrogen accumulation and CO_2 evolution in the salt-treated soil will be decreased when the concentration of salt added is beyond the optimum concentration. This stimulating or toxical effect of chloride salt used will occur in the same manner on CO_2 release at the same concentration of the same salt. This ties in with the point that amount of NH_4-N release is directly related to the amount of CO_2 release in the soil.

Nitrification which occurs in amended soil generally does not show highly significant difference when different salt concentrations were added; also the amount of NO_3-N release was nearly the same as that liberated from unamended soil. Presumably, this means that nitrification is not concentration dependent, but is either cation valence or time dependent. The production of nitrate nitrogen release fluctuated with increasing time of incubation and cation valence of chloride salt.

To further study the effect of temperature on soil nitrogen and CO_2 release in soil, three temperature levels of 30, 45, and 65°C were conducted for this experiment, and concentrations of NaCl, $CaCl_2$ and $AlCl_3$ were added, ranging from 0.0, 0.001, 0.01, 0.1, and 1.0 M. The results of this experiment showed increasing amounts of NH_4-N and CO_2 release with increasing temperature at any concentration of cation valence of chloride salts added. At the same time these temperatures were detrimental to nitrification. In most cases, NO_3-N was lost from the soil during the last two weeks. There was no definite or conclusive trend of NO_3-N accumulation in Akaka soil with increasing temperature.

Ammonification was generally enhanced by an increase in temperature, even at 65°C, a temperature at which most microorganisms, except spore-forming bacteria, are killed.

To extend the knowledge on which activity, chemical or biological, played the more important role in available nitrogen and CO_2 release in the soil, sterile Akaka soil was used for the third study. NaCl at different concentrations ranging from 0.0, 0.001, 0.01, 0.1, and 1.0 molar were added to sterile soil and incubated at room temperature. The results show that even in a system free of microbial activities,

NH_4-N and CO_2 were still released from the soil, whereas NO_3-N was lost from the soil. This shows that NO_3-N production is due to microbial activity in soil and no nitrate will be produced in soils lacking in microorganisms once volatilization of nitrate occur. Ammonium nitrogen production was concluded to be due mainly to microbial activity in the soil and less due to chemical activity because the amount of NH_4-N release in sterile soil was less than that released in non-sterile soil at the same environment.

The results obtained from this investigation suggest that available nitrogen and CO_2 release in Akaka soil were due mainly to the microbial activities in the soil, although some of NH_4-N release was obtained from chemical activities. High temperature had a stimulating effect on NH_4-N and CO_2 release but was toxic to NO_3-N liberation. The toxicity of high concentrations of salts used on soil nitrogen and CO_2 release depends on the cation valence of salt used, time of incubation and temperature. Different salts, or even the same salt at different temperatures, had different optimum concentrations where maximum nitrogen transformation and CO_2 evolution occurred.

TABLE I. EFFECT OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON AVAILABLE NITROGEN RELEASE IN AKAKA SOIL AT ROOM TEMPERATURE

Molar Concentration	Salt	INCUBATION PERIOD (WEEKS) 1 NH_4-N	1 NO_3-N	1 TOTAL	2 NH_4-N	2 NO_3-N	2 TOTAL	3 NH_4-N	3 NO_3-N	3 TOTAL	4 NH_4-N	4 NO_3-N	4 TOTAL
	NaCl						ppm. N						
0.0		3 a	9 b	12	1 a	9 b	10	-2 a	6 a	4	82 a	9 a	91
0.1		15 b	3 a	18	55 b	4 a	59	110 b	8 ab	118	74 a	12 ab	86
0.3		36 c	1 a	37	105 d	7 ab	112	155 c	13 c	168	146 b	18 c	164
0.5		50 d	2 a	52	120 d	5 a	125	151 c	13 c	164	198 c	9 a	207
0.7		50 d	2 a	52	142 e	7 ab	149	191 d	12 bc	203	242 d	13 b	255
1.0		50 d	3 a	53	166 f	7 ab	173	217 d	11 bc	228	266 e	11 ab	277
2.0		15 b	2 a	17	86 c	10 b	96	119 b	11 bc	130	190 c	11 ab	201
Significance		**	*		**	*		**	*		**	*	
	$CaCl_2$												
0.0		6 a	8 ab	14	28 b	0 a	28	-1 a	9 ab	8	-10 a	8 ab	-2
0.1		83 c	7 ab	90	94 c	6 cd	103	95 b	13 b	108	128 b	8 ab	136
0.3		128 d	9 ab	137	154 d	8 d	162	172 c	7 ab	179	209 c	7 ab	216
0.5		136 e	7 ab	143	163 d	3 b	166	208 d	11 ab	219	245 d	6 ab	251
0.7		115 d	3 ab	118	172 d	9 d	181	233 e	4 a	237	236 d	5 a	241
1.0		28 b	2 a	30	54 b	5 bc	59	203 d	5 ab	208	221 cd	7 ab	231
2.0		0 a	12 b	12	-15 a	8 d	-6	176 c	3 a	179	-19 a	10 b	-9
Significance		**	*		**	**		**	*		**	*	
	$AlCl_3$												
0.0		-25 b	5 bc	-20	-13 b	7 ab	-6	10 b	9 ab	19	45 b	8 b	53
0.1		121 f	4 bc	125	290 e	11 abc	301	294 d	3 a	297	306 d	14 b	320
0.3		77 e	1 ab	78	240 d	4 a	244	322 e	6 ab	328	395 e	6 b	401
0.5		14 d	0 ab	14	38 c	2 a	40	75 c	5 a	80	147 c	3 b	150
0.7		-12 c	8 c	-4	-6 b	11 abc	5	6 b	10 ab	16	28 b	2 b	30
1.0		-23 b	10 c	-13	-25 ab	15 bc	-10	-18 ab	16 b	-2	32 b	4 b	36
2.0		-56 a	-13 a	-69	-44 a	19 c	-25	-47 a	34 c	-13	-8 a	44 a	35
Significance		**	**		**	*		**	**		**	**	

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

TABLE II. EFFECT OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON CO_2 RELEASE IN THE AKAKA SOIL AT ROOM TEMPERATURE

Molar Concentration	Salts	INCUBATION PERIOD (WEEKS) 1	2	3	4
	NaCl	mg. of C/25 g. soil			
0.0		11.6 b	9.6 b	8.9 g	5.9 ab
0.1		12.1 bc	6.2 ab	5.7 a	7.7 bc
0.3		13.4 e	6.7 ab	6.2 b	6.9 abc
0.5		13.8 e	7.0 ab	7.3 e	5.1 a
0.7		13.1 e	8.7 b	6.5 c	7.8 bc
1.0		12.5 c	9.0 b	7.8 f	8.0 c
2.0		8.9 a	4.0 a	6.9 d	7.8 bc
Significance		**	**	**	*
	$CaCl_2$				
0.0		7.0 b	3.9 b	3.9 b	4.6 bc
0.1		11.6 c	5.2 c	4.7 bc	4.8 cd
0.3		9.6 c	5.7 d	5.2 bc	4.9 d
0.5		10.7 c	6.7 e	4.9 bc	4.4 b
0.7		9.7 c	9.3 f	5.6 c	4.4 b
1.0		6.1 ab	4.1 b	9.6 d	5.6 e
2.0		2.3 a	0.4 a	0.8 a	0.6 a
Significance		**	**	**	**
	$AlCl_3$				
0.0		5.5 c	4.6 bc	5.3 c	4.8 c
0.1		14.7 e	10.5 c	7.3 d	4.9 c
0.3		9.8 d	12.7 d	8.7 e	7.2 e
0.5		5.3 c	3.2 ab	3.4 b	5.5 d
0.7		2.9 ab	1.8 a	1.4 a	1.2 a
1.0		2.2 a	1.4 a	1.3 a	1.1 a
2.0		3.2 b	2.0 a	1.7 a	1.6 b
Significance		**	**	**	**

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

TABLE III. ANALYSIS OF VARIANCE FOR THE EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON AVAILABLE NITROGEN AND CARBON DIOXIDE RELEASE IN AKAKA SOIL AT ROOM TEMPERATURE

Source of Variation	DF	Mean Square
NH_4-N		
Salt (St)	2	23208.07**
Time (Tm)	3	100686.59**
St x Tm	6	3775.15**
Concentration (Conc)	6	84962.20**
St x Conc	12	53593.36**
Tm x Conc	18	3413.44**
St x Tm x Conc	36	4076.60**
Error	84	75.27
NO_3-N		
Salt (St)	2	69.22**
Time (Tm)	3	38.36**
St x Tm	6	9.56**
Concentration	6	12.48**
St x Conc	12	11.18**
Tm x Conc	18	6.65**
St x Tm x Conc	36	8.48**
Error	84	9.18
CO_2		
Salt	2	193.60**
Time	3	130.57**
St x Tm	6	10.59**
Concentration	6	59.92**
St x Conc	12	38.59**
Tm x Conc	18	6.77**
St x Tm x Cone	36	4.72**
Error	84	0.16

**Significance at 0.01 level.

TABLE IV. EFFECT OF DIFFERENT CONCENTRATIONS OF NaCl ON AVAILABLE NITROGEN RELEASE IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Concentration	Temp.	INCUBATION PERIOD (WEEKS) 1			2			3			4		
		NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL
	30°C						ppm. N						
0.0		0 a	-4 ab	-4	34 a	-4 b	30	84 a	7 b	91	101 b	13 b	114
0.001		21 b	-4 ab	17	86 ab	-5 ab	81	81 a	9 b	90	56 a	-7 a	49
0.01		43 c	-8 a	35	63 a	-7 a	56	92 a	11 b	103	86 b	-4 a	82
0.1		35 bc	-4 ab	31	165 b	-7 a	158	199 b	-4 a	195	177 c	-5 a	172
1.0		185 d	-2 b	183	255 c	4 c	259	363 c	-7 a	356	289 d	0 a	289
Significance		**	*		**	**		**	*		**	**	
	45°C												
0.0		280 b	5	285	354 b	14 b	368	476 bc	4 a	480	472 ab	-9 a	463
0.001		294 b	5	299	366 b	5 a	371	422 ab	18 b	440	440 a	5 bc	445
0.01		297 b	11	308	422 bc	13 b	435	466 bc	11 ab	477	508 b	4 bc	512
0.1		291 b	7	298	479 c	11 b	490	501 c	11 ab	512	516 b	0 ab	516
1.0		81 a	7	88	146 a	13 b	159	386 a	11 ab	397	433 a	14 c	447
Significance		**			**	**		*	*		*	**	
	65°C												
0.0		549 d	9	558	304 a	5 a	309	569 c	7 a	576	766 c	14 b	780
0.001		254 a	5	269	578 d	9 a	587	548 bc	15 a	563	700 bc	5 ab	705
0.01		387 c	7	394	505 c	16 ab	521	511 b	4 a	515	595 ab	9 b	604
0.1		331 b	10	341	472 c	16 ab	488	516 b	12 a	528	587 a	-6 a	581
1.0		254 a	12	266	393 b	23 b	416	364 a	25 b	389	523 a	9 b	532
Significance		**			**	*		**	**		**	*	

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

TABLE V. EFFECT OF DIFFERENT CONCENTRATIONS OF $CaCl_2$ ON AVAILABLE NITROGEN RELEASE IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Concentration	Temp.	INCUBATION PERIOD (WEEKS) 1			2			3			4		
		NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL
	30°C					ppm. N							
0.0		0 a	-4	-3	34 a	-4	30	84 a	7	91	101 ab	13 c	114
0.001		118 b	7	125	-9 a	1	-8	118 a	7	125	74 a	0 b	74
0.01		99 b	-2	97	144 b	-9	135	99 a	-2	97	121 ab	-5 a	116
0.1		223 c	1	224	129 b	-5	124	223 b	1	224	284 b	-5 a	279
1.0		318 d	0	318	237 c	-3	234	318 c	3	321	325 c	-4 ab	321
Significance		**	*		**	*		**			**	**	
	45°C												
0.0		280 c	3 ab	283	354 d	14 b	368	476 b	4 a	480	472 c	-9 a	463
0.001		208 b	5 ab	213	229 b	-7 a	222	424 b	13 b	437	538 d	2 b	540
0.01		535 d	14 b	549	277 c	-2 a	275	448 b	-2 a	446	244 a	-2 b	242
0.1		282 c	-6 a	276	343 d	-9 a	334	481 b	1 a	482	253 a	13 c	266
1.0		34 a	-4 ab	30	78 a	2 a	80	341 a	-4 a	337	327 b	11 c	338
Significance		**	*		**	*		*	*		**	**	
	65°C												
0.0		549 d	9 c	558	304 b	5	309	562 b	7 ab	569	766 a	14 ab	780
0.001		226 c	-8 a	218	213 a	-5	208	486 a	7 ab	493	939 bc	9 a	948
0.01		180 ab	-8 a	172	202 a	3	205	556 ab	16 b	572	891 b	14 ab	905
0.1		146 a	-5 ab	141	242 a	-6	233	544 ab	7 ab	551	969 bc	15 b	984
1.0		203 bc	5 bc	208	213 a	-3	210	493 a	1 a	494	1019 c	11 ab	1030
Significance		**	*		*			*	*		*	*	

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

TABLE VI. EFFECT OF DIFFERENT CONCENTRATIONS OF $AlCl_3$ ON AVAILABLE NITROGEN RELEASE IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Concentration	Temp.	INCUBATION PERIOD (WEEKS) 1			2			3			4		
		NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL
	30°C					ppm. N							
0.0		101 b	-4	97	124 ab	-6	118	105 a	0	105	11 a	4	15
0.001		160 c	-6	154	129 bc	-4	125	146 b	0	146	52 b	0	52
0.01		174 c	-2	172	214 cd	3	217	277 c	0	277	176 c	2	178
0.1		343 d	0	343	375 d	-7	368	463 d	7	470	433 d	13	446
1.0		75 a	2	77	90 a	2	92	126 ab	5	131	14 a	0	14
Significance		**			**			**			**		
	45°C												
0.0		247 c	-4	243	273 ab	0	273	428 b	5	433	519 d	5	524
0.001		543 e	7	550	372 b	-5	367	426 b	2	428	395 b	9	404
0.01		336 d	5	341	404 b	-2	402	468 c	13	481	462 c	-2	460
0.1		240 b	7	247	545 b	-4	541	584 d	13	597	591 e	4	595
1.0		23 a	9	32	172 a	5	177	146 a	7	153	250 a	0	250
Significance		**			**			**			**		
	65°C												
0.0		366 ab	0	366	387 a	2 b	389	428 a	0 b	428	647 a	0	647
0.001		377 ab	0	377	517 b	-7 a	510	490 b	-8 a	482	648 a	11	659
0.01		325 a	4	329	454 ab	-8 a	446	568 cd	16 c	584	602 a	6	608
0.1		338 a	2	340	451 ab	2 b	453	525 bc	0 b	525	679 a	14	693
1.0		401 b	-1	400	676 c	7 c	683	591 d	2 b	593	990 b	11	1001
Significance		**			**	*		**	**		**		

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

TABLE VII. ANALYSIS OF VARIANCE FOR THE EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON NH_4-N RELEASE IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Source of Variation	DF	Mean Square
NH_4, 65°, 45°, 30°C		
Salt (St)	2	44195.42**
Temperature (Tp)	2	3671683.82**
St x Tp	4	19633.60**
Time (Tm)	3	765307.10**
St x Tm	6	66596.51**
Tp x Tm	6	258641.53**
St x Tp x Tm	12	50480.60**
Concentration (Conc)	4	66182.22**
St x Conc	8	28834.60**
Tp x Conc	8	148692.78**
Tm x Conc	12	17500.94**
St x Tp x Conc	16	51557.16**
St x Tm x Conc	24	9930.13**
Tp x Tm x Conc	24	14907.53**
St x Tp x Tm x Conc	48	10425.31**
Error	180	479.23

**Significance at 0.01 level.

TABLE VIII. ANALYSIS OF VARIANCE FOR THE EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON NO_3-N RELEASE IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Source of Variation	DF	Mean Square
NO_3-N at 65°, 45°, 30°C		
Salt (St)	2	27.86**
Temperature (Tp)	2	68.78**
St x Tp	4	15.99**
Time (Tm)	3	22.49**
St x Tp	6	11.27**
Tp x Tm	6	5.44**
St x Tp x Tm	12	4.31**
Concentration (Conc)	4	3.68**
St x Conc	8	5.06**
Tp x Conc	8	3.84**
Tm x Conc	12	3.27**
St x Tp x Conc	16	2.08*
St x Tm x Conc	24	3.17**
Tp x Tm x Conc	24	4.19**
St x Tp x Tm x Conc	48	3.71**
Error	180	18.55

**Significance at 0.01 level.
*Significance at 0.05 level.

TABLE IX. EFFECTS OF DIFFERENT CONCENTRATIONS OF NaCl ON CO_2 RELEASE IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Concentration	Temp.	INCUBATION PERIOD (WEEKS) 1	2	3	4
	30°C		mg. of C/25 g. soil		
0.0		14.2 a	10.5	8.0 a	6.6 b
0.001		14.3 a	11.6	11.3 b	8.3 c
0.01		15.5 b	11.0	10.2 b	6.8 b
0.1		18.1 c	9.9	11.0 b	7.0 b
1.0		22.8 d	11.3	8.3 a	5.7 a
Significance		**		**	**
	45°C				
0.0		40.4 d	23.8 b	24.8 c	20.7 b
0.001		38.4 b	31.5 c	27.5 d	20.2 b
0.01		39.5 c	33.8 c	24.5 c	24.7 c
0.1		39.6 c	32.0 c	19.2 b	24.5 c
1.0		15.2 a	14.0 a	14.2 a	12.3 a
Significance		**	**	**	**
	65°C				
0.0		40.6 a	36.1 a	29.6 a	28.3 a
0.001		57.3 b	53.6 d	39.9 bc	30.1 a
0.01		53.8 b	42.2 b	37.8 b	32.3 ab
0.1		57.2 b	50.6 c	42.9 cd	37.6 bc
1.0		53.5 b	41.9 b	45.0 d	35.4 c
Significance		**	**	**	**

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

TABLE X. EFFECT OF $CaCl_2$ ON CO_2 RELEASE IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Concentration	Temp.	INCUBATION PERIOD (WEEKS) 1	2	3	4
	30°C		mg. of C/25 g. soil		
0.0		14.2 c	10.5 ab	8.0	6.6 a
0.001		11.7 a	10.9 b	10.4	10.2 c
0.01		12.3 b	9.9 a	8.6	8.6 b
0.1		16.8 d	10.7 ab	10.4	8.5 b
1.0		17.1 d	12.1 c	7.9	7.4 a
Significance		**	**		*
	45°C				
0.0		40.3 b	23.8 b	24.8 d	20.8 c
0.001		45.2 c	26.3 c	19.3 c	14.2 b
0.01		46.2 c	25.4 b	17.7 a	12.3 a
0.1		46.0 c	23.7 b	17.5 a	11.0 a
1.0		17.1 a	13.8 a	18.5 b	14.4 b
Significance		**	**	**	**
	65°C				
0.0		40.6 a	36.1 b	29.6	28.3 a
0.001		53.0 c	42.6 d	30.2	36.8 c
0.01		50.4 bc	38.2 c	32.0	31.9 ab
0.1		48.3 b	36.4 b	31.0	29.4 ab
1.0		48.9 b	33.2 a	30.0	33.3 bc
Significance		**	**		*

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

TABLE XI. EFFECT OF $AlCl_3$ ON CO_2 RELEASE IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Concentration	Temp.	INCUBATION PERIOD (WEEKS) 1	2	3	4
	30°C		mg. of C/25 g. soil		
0.0		19.7 b	13.0 c	13.9 b	11.4 c
0.001		21.5 c	12.3 bc	12.6 b	9.7 b
0.01		21.6 c	11.5 b	12.1 b	9.9 b
0.1		27.5 d	15.7 d	11.5 b	9.2 b
1.0		5.7 a	3.1 a	2.9 a	1.6 a
Significance		**	**	**	**
	45°C				
0.0		43.4 c	28.4 b	28.6 b	21.7 b
0.001		49.3 d	41.1 c	26.1 b	18.9 b
0.01		47.2 d	41.0 c	28.0 b	21.7 b
0.1		30.4 b	42.8 c	17.0 a	21.1 b
1.0		19.4 a	9.9 a	16.2 a	12.1 a
Significance		**	**	**	*
	65°C				
0.0		69.0 b	49.5 b	44.0 ab	39.3 bc
0.001		70.8 b	40.1 a	43.6 bc	47.9 d
0.01		60.0 a	36.8 a	38.6 a	39.8 c
0.1		59.9 a	34.0 a	39.3 a	35.6 ab
1.0		79.6 c	53.0 b	52.2 c	34.2 a
Significance		**	**	*	**

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

TABLE XII. ANALYSIS OF VARIANCE FOR THE EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON CO_2 EVOLUTION IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Source of Variation	DF	Mean Square
CO_2 at 65°, 45°, 30°C		
Salt (St)	2	662.32**
Temperature (Tp)	2	18980.19**
St x Tp	4	172.11**
Time (Tm)	3	3013.55**
St x Tp	6	37.55**
Tp x Tm	6	179.16**
St x Tp x Tm	12	69.74**
Concentration (Conc)	4	264.84**
St x Conc	8	50.39**
Tp x Conc	8	267.03**
Tm x Conc	12	21.48**
St x Tp x Conc	16	65.97**
St x Tm x Conc	24	9.67**
Tp x Tm x Conc	24	44.76**
St x Tp x Tm x Conc	48	20.60**
Error	180	1.55

**Significance at 0.01 level.

TABLE XIII. EFFECTS OF DIFFERENT CONCENTRATIONS OF NaCl ON AVAILABLE NITROGEN RELEASE IN STERILE AKAKA SOIL AT ROOM TEMPERATURE

Molar Concentration	INCUBATION PERIOD (WEEKS)											
	1			2			3			4		
	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL
0.0	17 abc	-5 a	12	26 b	-9 b	17	49 d	-18	31	22 a	-23	-1
0.001	6 ab	4 b	10	20 b	-19 a	1	4 a	-23	-19	9 a	-22	-13
0.01	44 bc	2 ab	46	20 b	-22 a	-2	31 c	-22	9	23 a	-14	9
0.1	53 c	0 ab	53	11 b	-22 a	-11	24 bc	-22	2	50 b	-14	36
1.0	-13 a	-3 ab	-16	-56 a	-13 b	-69	22 b	-25	-3	31 ab	-24	7
Significance	*	*		**	**		**			*		

TABLE XIV. EFFECT OF DIFFERENT CONCENTRATIONS OF NaCl ON CO_2 RELEASE IN STERILE AKAKA SOIL AT ROOM TEMPERATURE

Molar Concentration	INCUBATION PERIOD (WEEKS)			
	1	2	3	4
	mg. of C/25 g. soil			
0.0	5.6 b	2.3	3.2 b	2.0
0.001	5.4 ab	2.5	2.7 a	2.6
0.01	5.2 ab	2.5	2.6 a	2.6
0.1	5.4 ab	2.3	2.5 a	2.5
1.0	5.0 a	2.1	2.3 a	2.4
Significance	*		**	

**Significance at 0.01 level.
*Significance at 0.05 level.

Note: Means followed by the letters are significantly at the 5% level, if the letters are not the same.

TABLE XV. ANALYSIS OF VARIANCE FOR THE EFFECTS OF DIFFERENT CONCENTRATIONS OF SODIUM CHLORIDE SALT ON AVAILABLE NITROGEN AND CARBON DIOXIDE RELEASE IN AKAKA SOIL AT ROOM TEMPERATURE

Source of Variation	DF	Mean Square
NH_4 Sterile, Rm.		
Time	3	1113.58**
Concentration	4	2108.00**
Time x Conc	12	876.49**
Error	20	90.18
NO_3-N, Sterile, Rm.		
Time	3	966.24**
Concentration	4	7.07**
Time x Conc	12	45.81**
Error	20	12.90
CO_2, Sterile, Rm.		
Time	3	19.73**
Concentration	4	0.17**
Time x Conc	12	0.13**
Error	20	0.02

**Significance at 0.01 level.

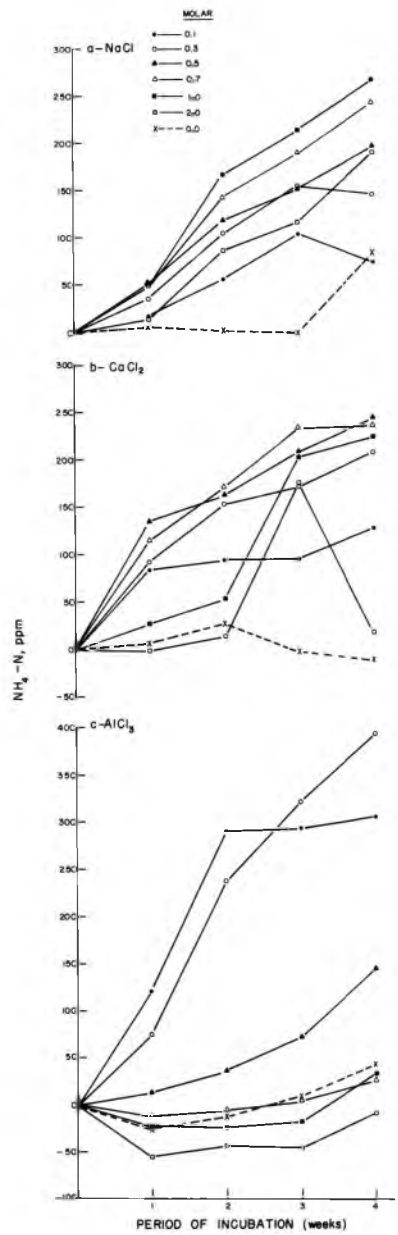

FIGURE 1. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON NH_4-N RELEASE IN AKAKA SOIL AT ROOM TEMPERATURE

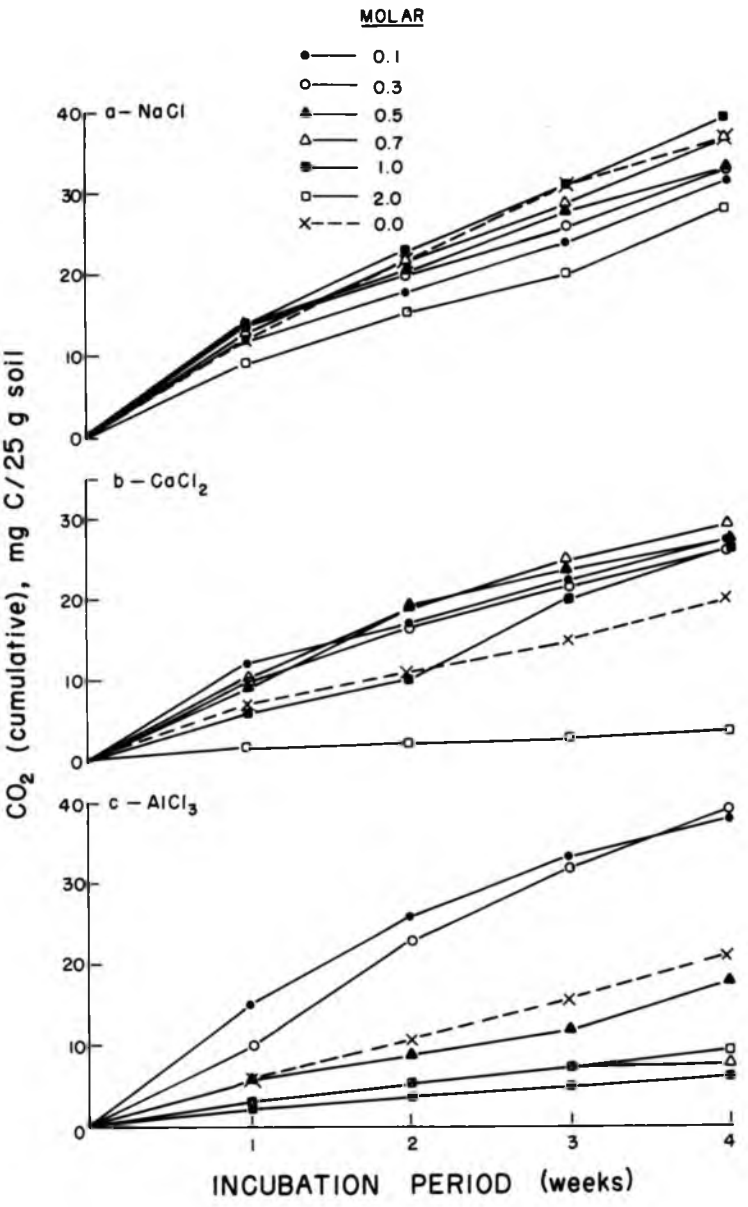

FIGURE 2. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON CO_2 RELEASE IN AKAKA SOIL AT ROOM TEMPERATURE

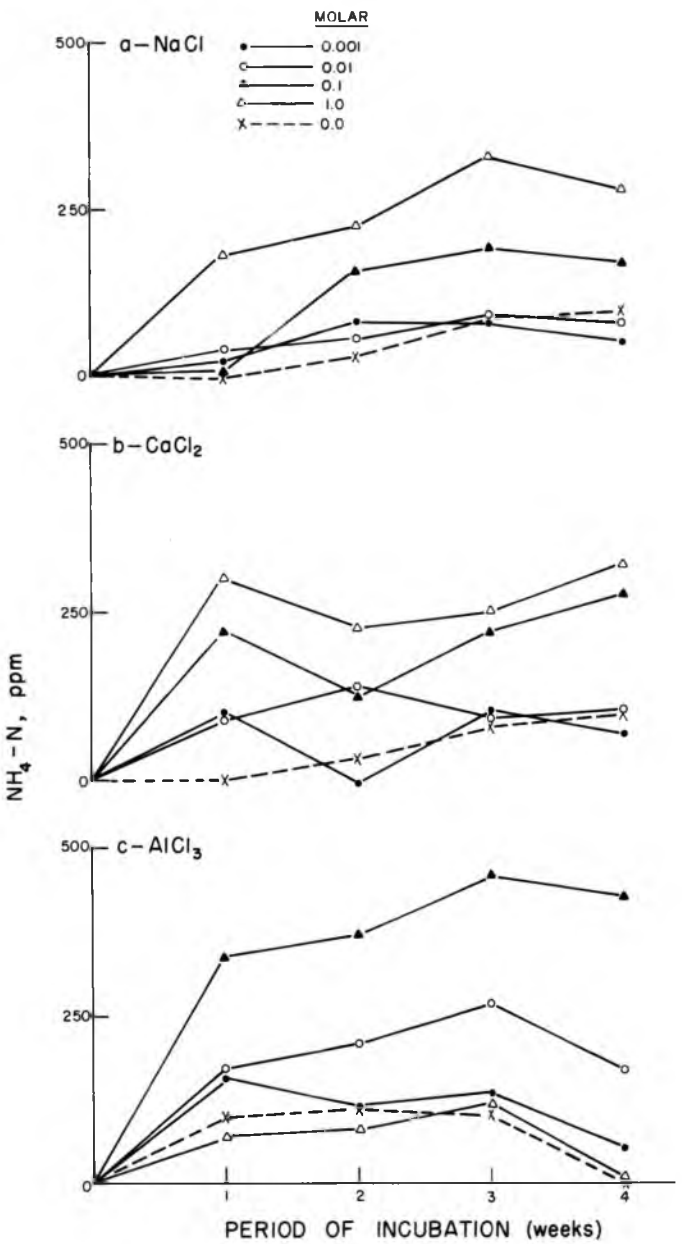

FIGURE 3. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON NH_4-N RELEASE IN AKAKA SOIL AT TEMPERATURE 30°C

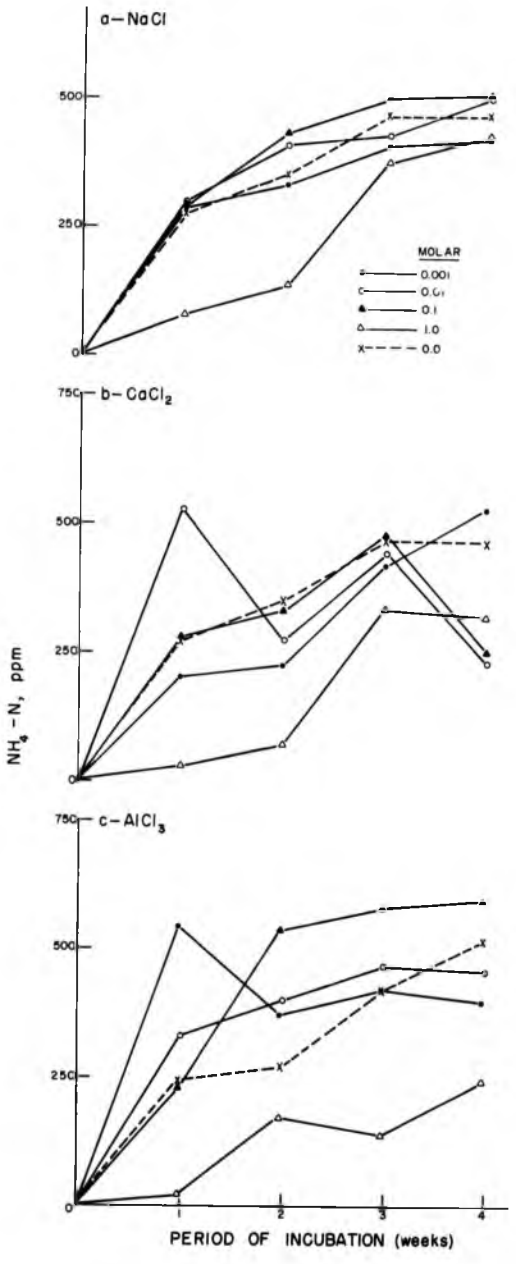

FIGURE 4. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON NH_4-N RELEASE IN AKAKA SOIL AT TEMPERATURE 45°C

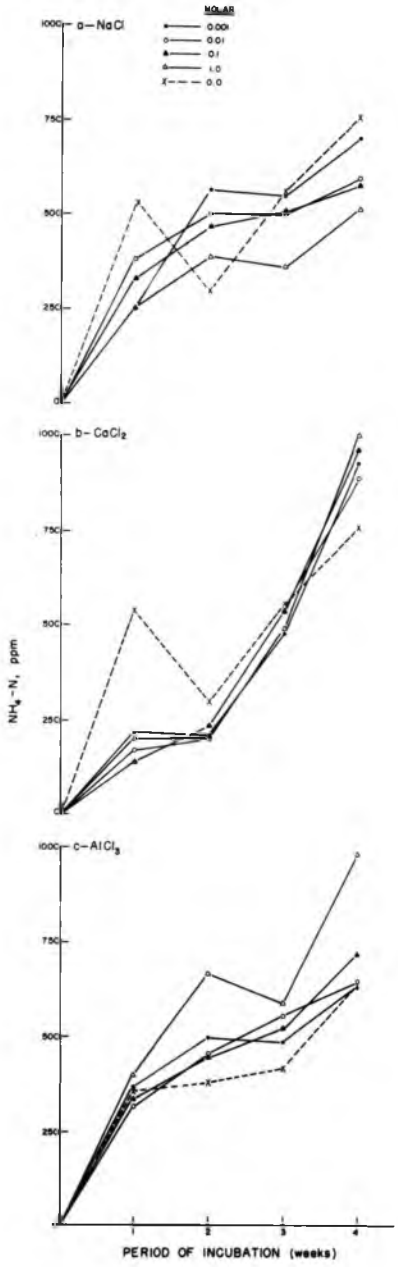

FIGURE 5. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON NH_4-N RELEASE IN AKAKA SOIL AT TEMPERATURE 65°C

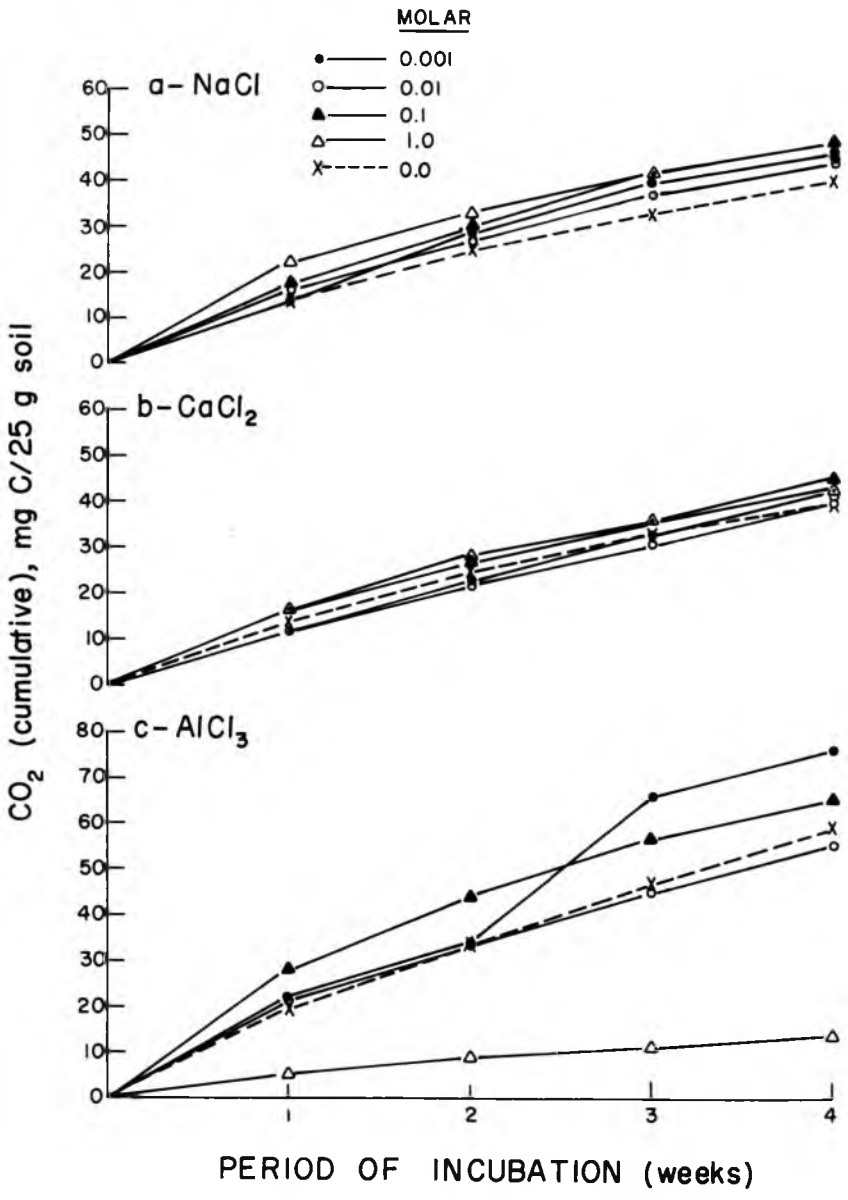

FIGURE 6. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON CO_2 RELEASE IN AKAKA SOIL AT TEMPERATURE 30°C

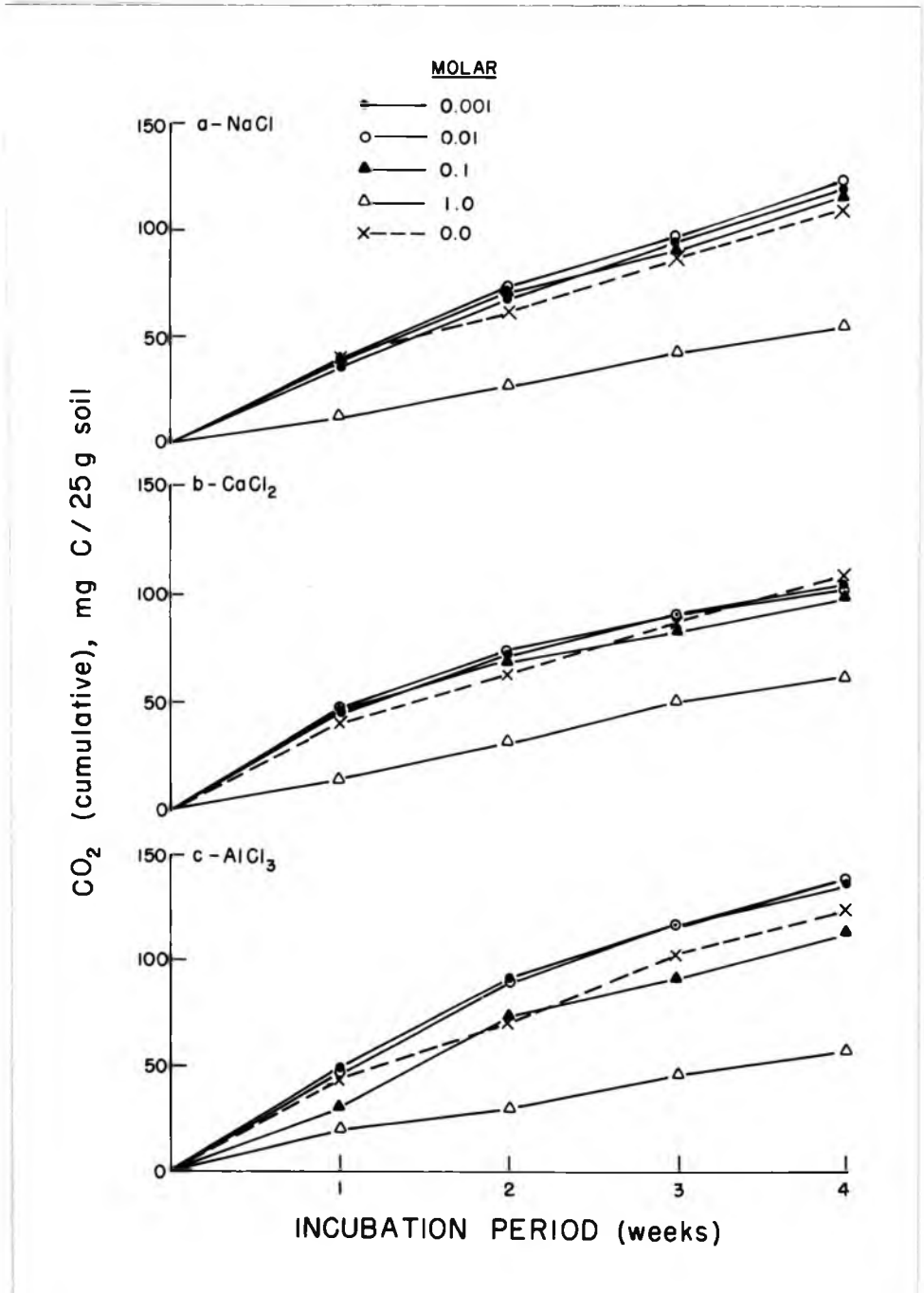

FIGURE 7. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON CO_2 RELEASE IN AKAKA SOIL AT TEMPERATURE 45°C

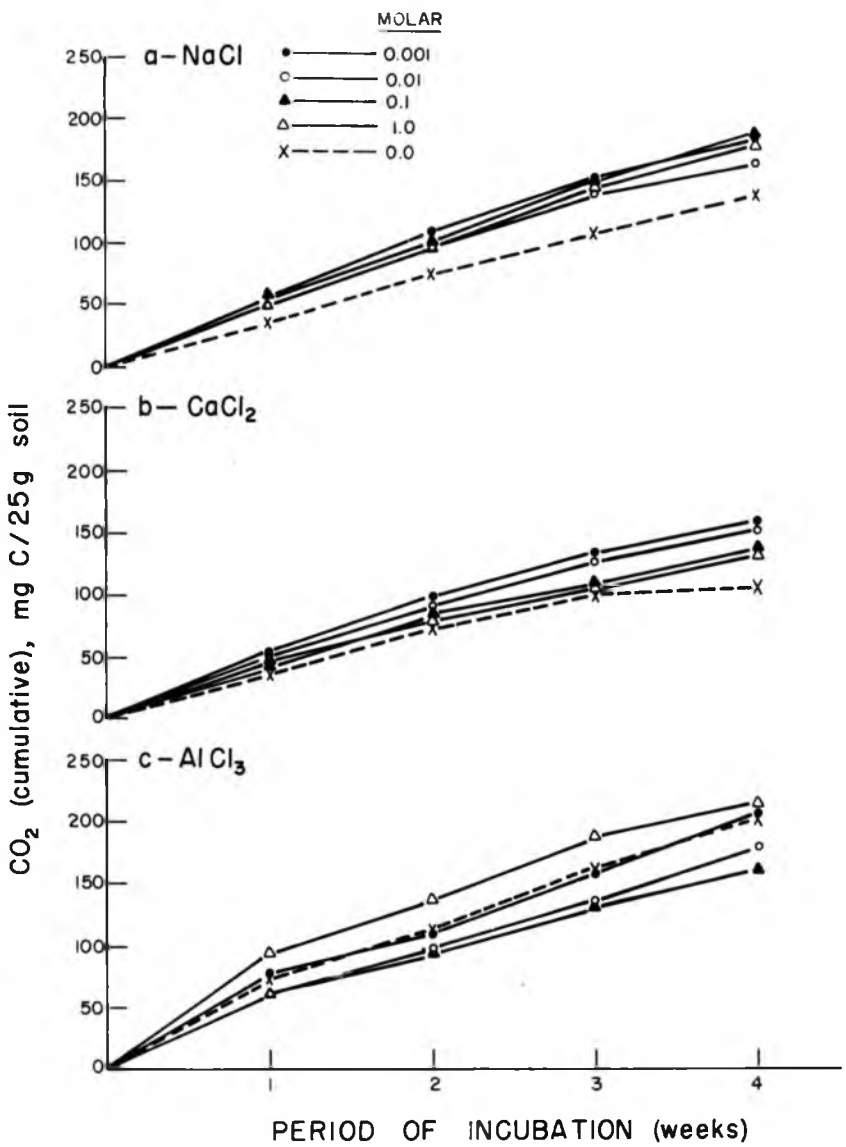

FIGURE 8. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON CO_2 RELEASE IN AKAKA SOIL AT TEMPERATURE 65°C

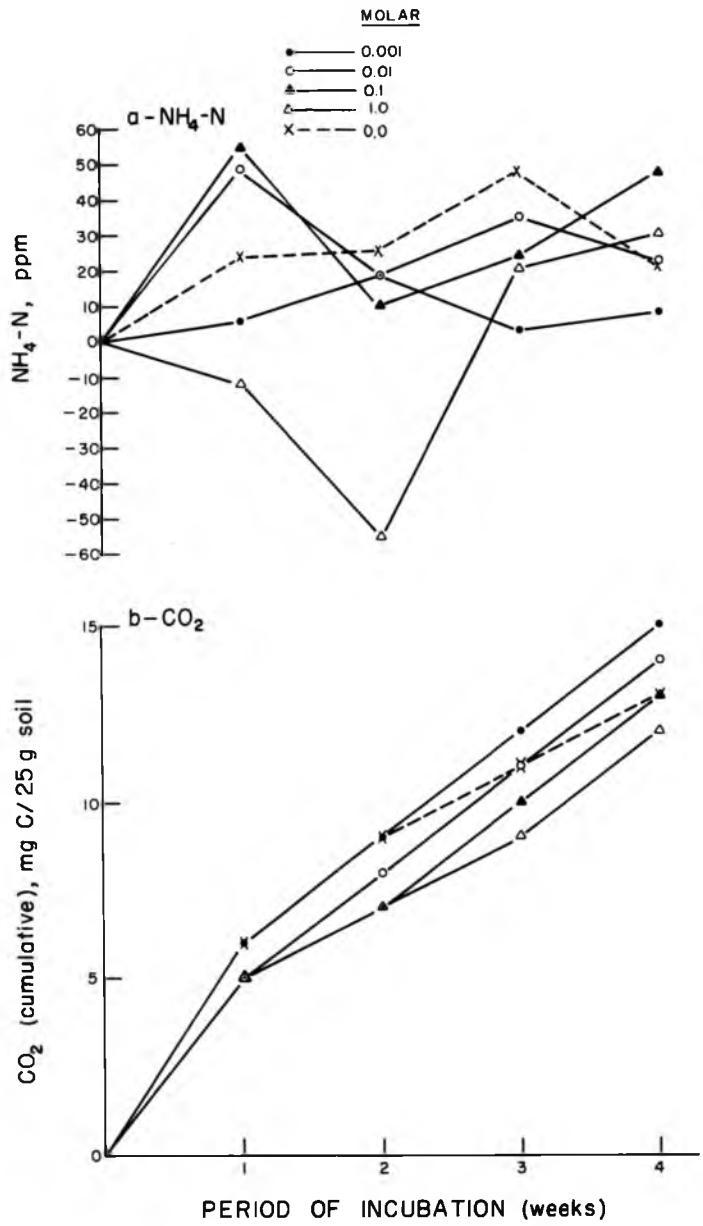

FIGURE 9. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON NH_4-N AND CO_2 RELEASE IN STERILE AKAKA SOIL AT ROOM TEMPERATURE

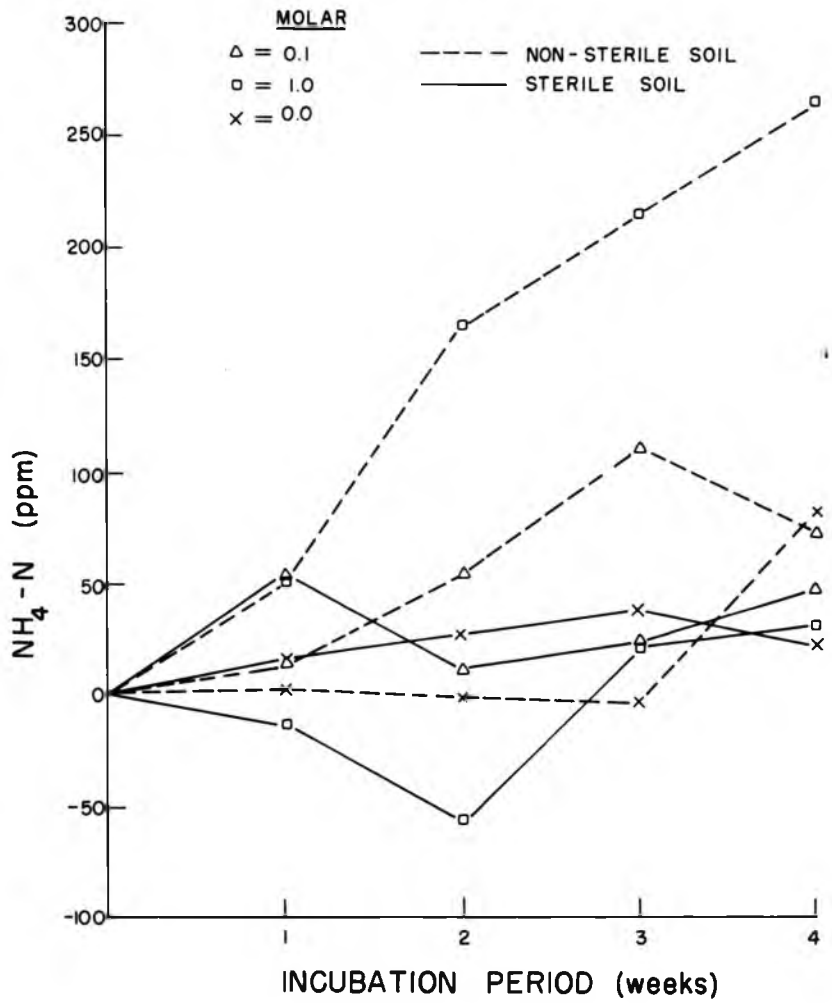

FIGURE 10. EFFECT OF STERILIZATION ON NH_4-N RELEASE IN AKAKA SOIL WITH DIFFERENT CONCENTRATIONS OF NaCl AT ROOM TEMPERATURE

APPENDIX

APPENDIX TABLE I. MEAN VALUES FOR AVAILABLE NITROGEN AND CO_2 RELEASE IN AKAKA SOIL AS AFFECTED BY DIFFERENT CONCENTRATION OF CHLORIDE SALTS AT ROOM TEMPERATURE

Source of Variation	Level	Mean of NH_4-N Release, ppm	Mean of NO_3-N Release, ppm	Mean of CO_2 Release, mg C
Salts	NaCl	108.22 b	8.12 b	8.40 c
	$CaCl_2$	115.71 c	6.70 a	5.61 b
	$AlCl_3$	77.31 a	8.89 c	4.87 a
Time (weeks)	1	38.61 a	3.99 a	8.89 d
	2	86.02 b	7.44 b	5.83 c
	3	127.03 c	9.99 c	5.43 b
	4	149.98 d	10.19 d	5.02 a
Concentration, M	0.0	10.36 a	7.16 a	6.33 cd
	0.1	138.85 f	7.60 a	7.99 e
	0.3	178.11 g	7.26 a	8.08 e
	0.5	128.72 e	5.53 a	6.44 d
	0.7	116.40 d	7.22 a	6.07 c
	1.0	97.49 c	8.01 a	5.76 b
	2.0	32.95 b	12.54 b	3.37 a

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

APPENDIX TABLE II. MEAN VALUES FOR AVAILABLE NITROGEN AND CARBON DIOXIDE RELEASE IN AKAKA SOIL AS AFFECTED BY DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS AT DIFFERENT TEMPERATURES (EXPERIMENT II)

Source of Variation	Level	Mean of NH_4-N Release, ppm	Mean of NO_3-N Release, ppm	Mean of CO_2 Release, mg C
Salt	NaCl	329.48 b	5.59 c	26.55 a
	$CaCl_2$	322.90 a	2.04 b	23.92 a
	$AlCl_3$	358.94 c	1.96 a	29.76 c
Temperature	65°C	498.29 c	5.62 c	42.71 c
	45°C	361.93 b	4.49 b	26.10 b
	30°C	151.10 a	-0.51 a	11.42 a
Time	1	240.56 a	1.88 a	36.79 d
	2	285.12 b	1.06 a	26.73 c
	3	377.83 c	5.83 c	23.21 b
	4	445.42 d	4.03 b	23.25 a
Concentration	0.0	323.58 b	3.37 a	26.41 b
	0.001	325.54 b	2.45 a	29.32 d
	0.01	339.94 c	2.98 a	27.65 c
	0.1	387.64 d	2.41 a	27.45 c
	1.0	308.86 a	4.79 b	22.90 a

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

APPENDIX TABLE III. MEAN VALUES OF AVAILABLE NITROGEN AND CO_2 RELEASE IN AKAKA SOIL AS AFFECTED BY DIFFERENT CONCENTRATIONS OF SODIUM CHLORIDE AT ROOM TEMPERATURE

Source of Variation	Level	Mean of NH_4-N Release, ppm	Mean of NO_3-N Release, ppm	Mean of CO_2 Release, mg C
Time (weeks)	1	21.56 b	-0.14 c	5.33 c
	2	4.13 a	-16.69 bc	2.42 a
	3	25.69 b	-21.91 a	2.73 b
	4	26.94 b	-19.40 ab	2.46 a
Concentration, M	0.0	28.29 c	-13.68	3.33 b
	0.001	9.66 b	-15.04	3.36 b
	0.01	29.41 c	-13.92	3.29 b
	0.1	34.58 c	-14.10	3.21 b
	1.0	-4.04 a	-15.94	2.99 a

Note: Means followed by the letters are significantly different at the 5% level, if the letters are not the same.

APPENDIX TABLE IV. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON AVAILABLE NITROGEN RELEASE (PPM) IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Conc.	Salts	Temp. °C	INCUBATION PERIOD (WEEKS) 1			2			3			4		
			NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL
0.001	NaCl	30	21	-4	17	86	-5	81	81	9	90	56	-7	49
		45	294	5	299	366	5	371	422	18	440	440	5	445
		65	254	5	269	578	9	587	549	15	564	700	5	705
		ster.	6	4	10	20	-19	1	4	-23	-19	9	-22	-13
	$CaCl_2$	30	118	7	125	-9	1	-8	118	7	125	74	0	74
		45	208	5	213	229	-7	222	424	13	437	538	2	540
		65	226	-8	218	213	-5	208	486	7	493	939	9	948
	$AlCl_3$	30	160	-6	154	164	-4	160	146	0	146	52	0	52
		45	543	7	550	372	-5	367	426	2	428	395	9	404
		60	377	0	337	520	-7	513	490	-8	482	648	11	659
0.01	NaCl	30	43	-8	35	63	-7	56	92	11	103	86	-4	82
		45	297	11	308	422	13	435	466	11	477	508	4	512
		65	387	7	394	505	16	521	512	6	518	596	9	605
		ster.	44	2	46	20	-22	-2	31	-22	9	23	-14	9
	$CaCl_2$	30	99	-2	97	144	-9	135	99	-2	97	121	-5	116
		45	535	14	549	277	-2	275	448	-2	446	243	-2	241
		65	180	-8	172	202	3	205	556	16	572	891	14	905
	$AlCl_3$	30	174	-2	172	214	-7	207	277	0	277	176	2	178
		45	336	5	341	404	-2	402	472	13	485	462	-2	460
		65	325	4	329	454	-8	446	568	16	584	605	6	611

APPENDIX TABLE IV. (Continued) EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON AVAILABLE NITROGEN RELEASE (PPM) IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Conc.	Salts	Temp. °C	INCUBATION PERIOD (WEEKS) 1			2			3			4		
			NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL
0.1	NaCl	30	35	-4	31	165	-7	158	199	-4	195	178	-5	173
		45	291	7	198	479	11	490	501	11	512	516	0	516
		65	331	10	341	471	16	487	516	12	528	587	-6	581
		ster.	53	1	54	11	-22	-11	24	-22	2	50	-14	36
	$CaCl_2$	30	223	1	224	129	-5	124	223	1	224	184	-5	279
		45	282	-6	276	343	-9	334	481	1	482	253	13	266
		65	146	-5	141	242	-6	233	544	7	551	969	15	984
	$AlCl_3$	30	343	0	343	375	-7	368	463	7	470	433	13	446
		45	240	7	247	545	-4	541	584	13	597	591	4	595
		65	338	2	340	451	3	454	525	0	525	679	5	684
1.0	NaCl	30	185	-2	183	255	4	259	363	-7	356	289	0	289
		45	81	7	88	146	13	159	386	11	397	433	14	447
		65	254	12	266	393	23	416	364	25	389	523	9	532
		ster.	-13	-3	-16	-56	-13	-69	22	-25	-3	31	-24	7
	$CaCl_2$	30	318	0	318	237	-3	234	318	4	322	325	-4	321
		45	34	-4	30	78	2	80	341	-4	337	327	11	338
		65	203	5	208	213	-3	210	493	1	494	1019	11	1030
	$AlCl_3$	30	75	2	77	90	2	92	115	5	120	14	0	14
		45	23	9	32	172	5	177	146	7	153	250	0	250
		65	401	-1	400	676	7	683	591	2	593	990	11	1001

APPENDIX TABLE IV. (Continued) EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON AVAILABLE NITROGEN RELEASE (PPM) IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Conc.	Salts	Temp. °C	INCUBATION PERIOD (WEEKS) 1			2			3			4		
			NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL	NH_4-N	NO_3-N	TOTAL
0.0 (Control)	NaCl	30	0	-4	-4	34	-4	30	84	7	91	101	13	114
		45	280	5	285	354	14	368	476	4	480	472	-9	463
		65	549	9	558	304	5	309	569	7	576	766	14	780
		ster.	17	-5	12	26	-9	17	49	-18	31	22	-23	-1
	$CaCl_2$	30	0	-4	-4	34	-4	30	84	7	91	101	13	114
		45	280	5	285	354	14	368	476	4	480	472	-9	463
		65	549	9	558	304	5	309	569	7	576	766	14	780
	$AlCl_3$	30	101	-4	97	124	-6	118	105	0	105	11	4	15
		45	283	-4	279	272	0	272	428	5	433	519	5	524
		65	366	0	366	387	2	389	428	0	428	647	0	647

APPENDIX TABLE V. EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON CARBON DIOXIDE EVOLUTION IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Conc.	Salts	Temperature	INCUBATION PERIOD (WEEKS) 1	2	3	4
			MG of C/25 g. soil			
0.001	NaCl	30°C	14	26	37	45
		45°C	38	70	98	118
		65°C	57	111	151	181
		Sterile-Rm	6	9	12	15
	$CaCl_2$	30°C	12	23	33	43
		45°C	45	71	90	104
		65°C	53	96	126	163
	$AlCl_3$	30°C	22	34	46	56
		45°C	49	90	116	135
		65°C	71	111	160	208
0.01	NaCl	30°C	16	27	37	44
		45°C	40	74	99	124
		65°C	54	96	134	166
		Sterile-Rm	5	8	11	14
	$CaCl_2$	30°C	12	22	31	40
		45°C	46	72	90	102
		65°C	50	88	120	152
	$AlCl_3$	30°C	21	33	45	55
		45°C	47	88	116	148
		65°C	60	97	136	176
.1	NaCl	30°C	18	29	40	47
		45°C	40	72	91	116
		65°C	57	108	151	189
		Sterile-Rm	5	7	10	13
	$CaCl_2$	30°C	17	28	38	47
		45°C	46	70	88	99
		65°C	48	85	116	146
	$AlCl_3$	30°C	28	44	56	65
		45°C	31	74	91	112
		65°C	60	94	133	169

APPENDIX TABLE V. (Continued) EFFECTS OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS ON CARBON DIOXIDE EVOLUTION IN AKAKA SOIL AT DIFFERENT TEMPERATURES

Molar Conc.	Salts	Temperature	INCUBATION PERIOD (WEEKS) 1	2	3	4
1.0	NaCl	30°C	23	34	42	47
		45°C	15	29	43	55
		65°C	54	96	141	177
		Sterile-Rm	5	7	9	11
	$CaCl_2$	30°C	17	29	37	45
		45°C	17	31	50	64
		65°C	49	82	112	145
	$AlCl_3$	30°C	6	9	12	14
		45°C	20	30	46	58
		65°C	80	133	185	219
0.0 (control)	NaCl	30°C	14	25	33	40
		45°C	40	64	89	110
		65°C	41	77	107	135
		Sterile-Rm	6	8	11	13
	$CaCl_2$	30°C	14	25	33	40
		45°C	40	64	89	110
		65°C	41	77	107	135
	$AlCl_3$	30°C	20	33	47	58
		45°C	44	73	102	124
		65°C	69	119	163	202

APPENDIX TABLE VI. OSMOTIC PRESSURE VALUES OF DIFFERENT CONCENTRATIONS OF CHLORIDE SALTS AT DIFFERENT TEMPERATURES

Molar Concentration	Salts	Osmotic Pressure (atm.)			
		Room	30°C	45°C	65°C
0.001	NaCl	0.049	0.050	0.052	0.055
	$CaCl_2$	0.074	0.075	0.078	0.083
	$AlCl_3$	0.099	0.099	0.104	0.111
0.01	NaCl	0.494	0.497	0.522	0.554
	$CaCl_2$	0.741	0.745	0.782	0.832
	$AlCl_3$	0.987	0.994	1.043	1.109
0.1	NaCl	4.936	4.970	5.215	5.543
	$CaCl_2$	7.405	7.454	7.823	8.315
	$AlCl_3$	9.873	9.938	10.430	11.086
0.3	NaCl	4.936			
	$CaCl_2$	7.405			
	$AlCl_3$	9.873			
0.5	NaCl	12.342			
	$CaCl_2$	37.023			
	$AlCl_3$	49.364			
0.7	NaCl	17.280			
	$CaCl_2$	51.832			
	$AlCl_3$	69.110			
1.0	NaCl	49.364	49.692	52.152	55.432
	$CaCl_2$	74.046	74.538	78.228	83.148
	$AlCl_3$	98.728	99.384	104.304	110.864
2.0	NaCl	98.728			
	$CaCl_2$	148.092			
	$AlCl_3$	197.456			

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